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PREFACE.

THIS treatise is divided into two parts. The first relates to the making and the maintaining of Macadamised Roads, while the second part deals with Carriageways and Footpaths.

Although much has been written on the subject of making and maintaining macadamised roads, the recent introduction of mechanical appliances for quarrying, manufacturing, and consolidating the metalling has led to important changes on the older methods, whereby more expeditious, effective, and economical work has been rendered possible. The effect of the transfer of the management of the highways to the County Councils by the Local Government Acts has afforded scope for road maintenance on a larger scale than has hitherto been practised in this country.

The information here given, which treats of all matters relating to the systematic making and repairing of roads and streets, is for the most part the result of experience of the practical work of constructing roads and their subsequent maintenance, extending over a considerable number of years. The methods of carrying out the work and the cost of each operation are given in detail, and, it is hoped, are now brought together in a useful form.

In the second part, all the recognised descriptions of material used in the paving of carriageways and footways, and the latest methods of construction adopted in the principal cities and towns of the kingdom, are described. The cost of forming pavements and the comparative wear are also given in detail. The congestion of pedestrian and vehicular traffic in the larger towns, and the means of obviating the delays inseparable from the present state of matters, are noticed at some length. The benefits likely to result from the construction of subways are also described in a concise manner, while other matters of general importance receive due and adequate notice.

The Author has throughout this treatise adhered to as systematic an arrangement as practicable. He trusts that it will meet the need for a detailed treatment of the subject according to the latest practice, which has mainly arisen from the altered conditions of transit during recent years.

T. A.

August, 1900.

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General Conclusions in regard to Macadamised Roads—Improvement of Gradients, Sharp Turnings, and Road-Surfaces tend to cheapen Transit—Motor Vehicles for Light and Heavy Traffic—Comparative cost of Metalling per mile of Road—Annual cost of repairing Roads per mile in the principal counties of England and Scotland; Quantity of Metalling applied and cost per cubic yard—Government Grants for the Relief of Local Taxation—Congestion of Wheel Traffic in the thoroughfares of cities and towns, with particular reference to those in the Metropolis—Proposed new thoroughfares in London—Loss of Money through delays to men of business, vehicles, and horses—Sir J. Wolfe Barry's remarks—Viagraph: Description and Use of—Profiles and Amount of Unevenness of the Surface of Roads—Autograph Records of Road-surfaces in different parts of the country compared, pp. 404–425

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ROAD MAKING AND MAINTENANCE.

HISTORICAL SKETCH.

Road Making.—Tredgold's definition of the profession of the Civil Engineer, which was adopted by the 'Institution of Civil Engineers' in their charter—viz., "The art of directing the great sources of power in nature for the use and convenience of man"—illustrates very forcibly the importance of road making as a branch of engineering practice.

The construction of roads or artificial ways is one of the first steps taken, with the spread of civilization, in opening up a country for the accommodation of travellers and the carriage of commodities.

Road makers may be looked upon as pioneers in the material advancement of a nation and in influencing society, the good condition in which roads are maintained being a fair indication of the progress or prosperity of any age or people.

The natural resources and manufactures of a country can only be developed by communication between towns and rural districts, or, in other words, "The road is so necessary an instrument of social well-being, that in every new colony it is one of the first things thought of. . . . The new country, as well as the old, can only be effectually opened up, as the common phrase is, by roads, and until these are made it is virtually closed."* The evolution of the modern road can only be adequately understood by reference to the practice of this interesting subject, from the time when the making of the great military roads of the Romans was carried out to the present time, authentic descriptions of which are recorded. It will be necessary, therefore, previous to detailing the different processes from the inception to the completion of roads and streets as now constructed, to review concisely the history of the subject, which extends over a period of 2200 years.

Roman Roads.—The Romans learned the art of making paved roads from the Carthaginians, and the highways constructed by them were

* Smiles' *Lives of the Engineers*, vol. i.

regarded as of vital importance for conquest and the maintenance of their Empire, while they were admirable models of engineering skill.

One of the oldest, and probably the most important of these paved military roads, called the 'Appian Way,' was commenced by Appius Claudius while holding the office of censor, in 312 B.C. Twenty-nine great military roads centred in Rome, many of which were carried in different directions to the extreme limits of the vast Empire, connecting the Capitol and the principal cities and strategic points.

These lines of communication, for a distance of 50 miles from Rome, were decorated on either side with temples and other superb edifices. Buildings were erected at regular distances alongside these roads at the public expense, and used as lodging-houses for changing horses to suit the wants of the couriers, and for the requirements of the army; mansions were also erected at intervals of from 30 to 36 miles for the accommodation of the soldiers.

Roman roads are remarkable for preserving a straight line from point to point regardless of obstacles, which by a slight detour could have been avoided. They were carried over marshes, lakes, ravines, and mountains, and have, by their bold inception, duration and stability, excited astonishment and admiration in all ages. The 'Appian Way' was not only the earliest military road, but the best constructed; and Statius, the poet, designates it as the Queen of Roads in his time. It extended to 360 miles; the portion from Rome to Capua, a distance of 142 Italian miles, was constructed during the censorship of Claudius. The remaining portion, extending in a south-easterly direction to Brundusium (now Brindisi), appears to have been carried out from time to time as the Romans conquered the states to the south. Julius Cæsar spent considerable sums of money on this road, and in all probability completed it to Brundusium. The mode of constructing this great military road was as follows:—

Two parallel trenches were excavated at a distance of about 40 feet apart to mark the width of the road, and also the direction which it was intended to follow. This at once gave the location of the road, and showed the nature of the subsoil, from which the level of the foundations was determined; all loose soil was removed, and replaced where necessary with suitable material, consolidated by ramming until a solid foundation was obtained for the support of the road materials.

This, in general, appears to have been composed of four layers of material having a total thickness of 3 feet, local stone being used when available, though at times the material was brought from a considerable distance. The lowest layer, or *statumen*, was formed of two courses of flat stones laid in mortar; over this was laid the *rudus*, or rubble, well beaten; then the third layer, called the *nucleus*, a sort of *beaton*, was spread, being composed of coarse gravel and lime, used hot, and on which was bedded the *summa crusta*.

When the road was carried over marshy ground, a framework of carpentry was provided, called '*contignata pavimenta*,' and the frame itself *contignationes*.

The joists or sleepers were termed *coaxationes* or *cassationes*, and were made of an oak called esculus, because it was not liable to warp or shrink. To protect the timber from the effect of the lime mixed with the other materials, it was covered with a bed of rushes or reeds, and sometimes straw. On this stratum of reeds or straw was laid the *statumen* or foundation.

The second bed was made of broken stones mixed with lime, which Isidore calls *rudus*. When this material was composed of stones freshly broken, it was called *rudus novum*, and quicklime was added in the proportion of one of lime to three of stone. But when the material came from old buildings, it was called *rudus redivivum*, and then an additional portion of lime was used, two parts to five, and the work termed *ruderationem*; the rammer or beater was employed to strengthen, equalize, and smooth it. This composition, whether formed of gravel or *débris*, was 9 inches in thickness after it had been thoroughly rammed.

FIG. 1.—Cross-section of Roman road ('Appian Way').

Over this *tarras* or *ruderation*, a cement was laid for the third bed, which was composed of bricks, potsherds, or broken tiles mixed with lime, in the proportion of one of lime to three of brick. This was spread over the *ruderation* in a thin layer to receive the fourth bed or paving, consisting of polygonal blocks jointed with the greatest nicety, serving as a covering to the entire work, and was called in consequence *summam crustam*. The third bed, or nucleus, was the softest layer of the whole, and was interposed between the harder layers. The stones and cement which formed the road were not less than 6 inches in thickness, and the entire mass laid upon the framework of carpentry was 15 inches. Fig. 1 shows a cross-section of the 'Appian Way,' and typifies many of the other great military roads in the neighbourhood of Rome. The paved portion was 16 feet wide, with margins on either side, separated by a curb 2 feet wide and 18 inches high, which served as seats for travellers. The margins were not paved with blocks, the finished surface being the gravel concrete; they were consequently at a lower level than and were only half the width of the centre portion.

The entire width of these military roads was from 36 to 40 Roman feet, the middle portion being for the infantry, while the margins were made use of by horses and carriages.

Of the other great military roads some were named after the Consuls and Emperors who had constructed them, such as the Flaminian and Domitian, while others were designated by the name of the province through which they passed, such as the Latian, Tiburtine, Campanian, and Praenestine ways.

Other roads constructed solely for civil purposes were connected with the great military ways and distinguished by the following names, *Via*, *Actus*, *Iter*, *Semita*, *Trames*, *Diverticulum*, *Divertium*, *Callais*, etc.*

Via answers to our common road; its breadth was 8 Roman feet, so that carriages could pass without collision.

Actus was a road for the passage of a single carriage; it derived its name from a measure used in surveying land, of which the breadth was 4 feet and the length 120 feet.

Iter was a road for pedestrians and horsemen, the breadth of which was 3 feet.

Semita was only half the breadth of the Iter, and when it crossed fields it was called *Trames*, *Diverticulum*, and *Divertium*.

Callais was a road through mountainous districts, for the purpose of attending the flocks.

"The unpaved roads of the Romans were called by Ulpian *vias terrenas*, to distinguish them from those dressed with stone or gravel, and they were regulated by similar laws and ordinances to the others. The road from Spain into Italy, through Nismes, was of this kind, and only passable during the summer months.

"In the winter and spring it was in a soft state, from the water which came down from the neighbouring mountains, though Strabo mentions several wooden and stone bridges and ferries. These roads, so liable to be broken up by the torrents, were exposed to the action of the sun and wind, all shade being removed, that they might speedily dry.

"The whole Roman Empire comprised eleven regions, viz., Italy, Spain, Gaul, British Isles, Illyria, Thrace, Asia Minor, Pontus, the East, Egypt, and Africa, and these were divided into 113 provinces, traversed by 372 great roads, which, according to the Itinerary of Antoninus, were together in length 52,964 Roman miles." †

In Peru the Incas appear to have built great roads. That from Quito to Cuzco was between 1500 and 2000 miles in length and 20 feet wide; it was situated at an elevation of over 12,000 feet above the sea level. This road was characterized by having a running stream and a row of trees on either side, while the road itself was paved with stones 10 feet square, and in some instances with stone covered with bitumen.

* Cresy's *Encyclopædia of Civil Engineering*, 1847. † *Ibid.*

Humboldt, in his *Aspects of Nature*, speaks of this mountain road as "a marvellous work, not inferior to the most imposing Roman roadways"; while Prescott, in his *History of Peru*, says of this road that "it was conducted over sierras covered with snow; galleries were cut through the living rock; rivers were crossed by means of bridges swung suspended in the air; precipices were scaled by stairways hewn out of the native bed, and ravines of hideous depth were filled up with solid masonry."

Among the many magnificent engineering works carried out by the Romans, the public roads ranked pre-eminently high, and great labour and expense were incurred in their construction. It is not to be wondered at, therefore, considering the importance of these works, that only those of the highest attainments were considered as having the necessary qualifications to supervise these great works of prominent utility.

Early French Roads.—As the Romans conquered states, roads were introduced for the benefit of commerce and society, and the art of constructing them on the Roman method was practised in France till about the beginning of the eighteenth century. A cross-section of these roads is shown in fig. 2.

The material forming the road was composed of flat stones laid by hand

FIG. 2.—Cross-section of French road (Roman method) previous to 1775.

in two or more layers for a width of 18 feet on the bottom of the excavation; on this foundation a layer of small stones was spread and beaten down, and the surface finished with a layer of stones broken smaller than the underlying material. The usual thickness of the body of the road was 18 inches in the centre and 12 inches at the sides. The roads in France down to the year 1764 were maintained by statute labour (*la corvée*) which was only effected twice annually, in the spring and autumn of each year, necessitating the application of large quantities of stones to carry the traffic during the intervals between repairs. After the suppression of statute labour (1764) the mode of constructing new roads was considerably modified, and in the year 1775 M. Trésaquet adopted the method shown in section at fig. 3. The excavated portion was made parallel to the finished surface of the road and 10 inches below it. The bed of stones was laid edgewise and beaten to an even surface, over which a second bed of smaller stones was laid by hand, the finishing layer being of broken stones the size of walnuts, and spread with a shovel. The rise of the road was 6 inches in the centre, the

material for finishing the road or upper surface being selected from the hardest quality of stone.

FIG. 3.—Cross-section of French road, as constructed by M. Trèsaquet in 1775.

Later French Roads.—This mode of constructing roads in France was practised till about the year 1820, when the system of Macadam attracted attention; the peculiar virtue of angular broken stones in consolidating and forming a hard surface was recognized, and the system was officially adopted in 1830 for constructing roads in that country.

M. Dumas, engineer-in-chief of the Ponts et Chaussées, writing in 1843,* stated that the system of Macadam was generally adopted in France, and that the roads were maintained in good condition by continuous and watchful attention in cleansing and repairing them, and realizing his motto, "The maximum of beauty."

Early British Roads.—The great Roman General Julius Cæsar carried out many paved roads in Italy, and, recognizing the vital importance of such lines of communication, extended them into the provinces; while subsequent to the year A.D. 43, main and branch roads were constructed in Britain by the Romans in almost every direction, from their military stations and camps to the coast.

"The Romans seem to have paid particular attention to the construction of roads in the distant provinces; and those of Britain, which may still be traced in various ramifications, present a lasting monument of the justice of their conception, the extent of their views, and the utility of their power. A grand trunk, as it may be called, passed from the south to the north, and another to the west, with branches in almost every direction that general convenience and expedition could require. What is called *Watling Street* led from Richborough, in Kent, the ancient Rutupiæ, north-east, through London to Chester. The *Ermine Street* passed from London to Lincoln, thence to Carlisle, and into Scotland. The *Foss Way* is supposed to have led from Bath and the western regions, north-east, till it joined the Ermine Street. The last celebrated road was 'Ikeneld' or 'Ikneld,' supposed to have extended from near Norwich, southward into Dorsetshire." †

Although there is no trace of Roman influence in the construction of later roads in Britain, still in many cases those made by them form the

* *Annales des Ponts et Chaussées*, 1843.

† Pinkerton's *Geography*, vol. i. p. 20.

foundations of existing roads in different parts of the country. Many traces of the remains of Roman Roads, often situated at a considerable depth below the surrounding ground of the present day, have been discovered from time to time. One of the latest discoveries was disclosed when carrying out storm-water drainage works at Rochester in 1897, the details of which may be given.

"When the Romans made the great way from the Kentish coast to the north of England, a wooden bridge, built upon piles, was thrown across the Medway. On reaching the Strood side of the river the engineers were confronted with a marsh of about 355 yards in width. This difficulty they boldly overcame by constructing upon the alluvial deposit a magnificent causeway.

"A section of the buried work showed the following:—(1) Layers of post-Roman roads for a depth of 2 feet 8 inches; (2) paved surface of causeway, 6 inches to 8 inches; (3) small pebble gravel, mixed with black earth, rammed, 9 inches; (4) flints, broken fine, 7 inches; (5) rammed chalk, 5 inches; (6) flints (white, and rather large), rough pieces of Kentish rag, fragments of Roman tile, 3 feet 6 inches; (7) marsh mud, containing numerous oak piles about 4 feet in length, with pieces of wood laid at intervals across them, or perhaps they were originally made fast by nails. The width of the causeway was about 14 feet, while the distance apart of the wheels of the waggons has been estimated, from the grooved wheel-track, at $4\frac{1}{2}$ feet." *

The construction of this part of the road passing through Rochester corresponds very nearly with that described at page 3, and designated *contignata pavimenta*, being the method adopted by the Romans when forming roads across marshes in Italy.

The depth of the material forming the roadway, above the timber foundation, amounting to 5 feet 10 inches, appears to be considerable greater than that usually adopted by the Romans in similar circumstances.

For a considerable period after the occupation of Britain by the Romans the roads made by them were the only means of internal communication, but during the Dark Ages they were allowed to fall out of repair and finally into ruin, and were in many instances overrun with forest and waste until they assumed a condition probably the worst in Europe. At this period communication between towns was both difficult and dangerous; the roads which formerly had such a beneficial effect on the country were regarded with terror as aids to plunder, and in the year 1285 owners of land were enjoined to widen the roads, by cutting down trees on each side to a certain width, the inland commerce, such as it was,

* The foregoing description is abstracted from a pamphlet on "Roman Discoveries," by G. Payne, F.L.S., F.S.A., reprinted from *Archæologia Cantiana*, 1898.

being maintained principally by rude paths or horse-tracks, traversed by pack-horses.

"In very early periods of English civilization, while the population was thin and scattered, and men lived by hunting and pastoral pursuits, the track across the down, the heath, and the moor sufficiently answered their purpose. Yet, even in these districts unencumbered with wood, where the first settlements were made—as in the downs of Wiltshire, the moors of Devonshire, and the wolds of Yorkshire—stone tracks were laid down by the tribes between one village and another. In some districts they are called trackways or ridgeways, being narrow causeways usually following the natural ridge of the country, and probably serving in early times as local boundaries. On Dartmoor they are constructed of stone blocks, irregularly laid down on the surface of the ground, forming a rude causeway of about 5 feet or 6 feet wide." *

"In 1346 a law was passed to levy a toll on some of the roads leading out of London, which were reported to be impassable. In the reign of Henry VIII. (1509-1547) laws were enacted binding the several parishes to take care of the roads, and annually to select qualified persons to superintend them; but simple as are the principles of road making, those appointed are seldom sufficiently instructed on the subject, and being ratepayers, are too much interested to allow of the requisite outlay. Thus many of the parish roads are in a wretched condition, the system adopted by most parish surveyors being merely to fill up the ruts and inequalities with stones picked from the surface of the land, or gravel dug in some convenient spot; this operation repeated in the spring and autumn constitutes their whole duty; no attention being paid to the nature of the soil, or the selection of the material that will bind with it to form a hard exterior crust." †

No serious attempt was made, however, to restore the highways until the introduction of the turnpike system, after the restoration of Charles II. Acts were passed in the year 1653 for widening and repairing some of the public roads, and turnpike gates were first legally erected in England in 1663. The first relates to that from London to Scotland, which passed through Hertford, Cambridge, and Huntingdon, where toll was levied on all but foot-passengers, owing to the road becoming very bad through the heavy loads of barley passing over them in wagons and carts.

The roads in Scotland, although having lighter traffic and better materials for repairs, were said to be in an equally unsatisfactory state. The first stage-coach in Scotland was run between Edinburgh and Leith in 1610. In 1658 there was a fortnightly stage-coach between Edinburgh and London, but it was afterwards discontinued for many years. Acts

* Smiles' *Lives of the Engineers.*

† Cresy's *Encyclopædia of Civil Engineering*, 1847.

were passed in the Scottish Parliament of 1661, 1669, 1670, 1685, and 1686, having reference to the making, up-keep, and control of roads, and many other Acts of a local as well as general application were subsequently passed into law for the improvement of public roads. These had reference chiefly to statute labour roads as a means of communication in the different parishes.

The unsettled state of the country in the Northern and Western Highlands of Scotland, culminating in the rebellion of 1715, brought about the necessity for making roads through the heart of these mountainous strongholds. The carrying out of these was entrusted to General Wade, who, between the years 1726 and 1737, constructed about 250 miles of roads, which were of the greatest value to the country. For the most part the width of these roads was 16 to 18 feet, and they had a pitched foundation covered with small stones and gravel. Many exciting scenes were enacted in close proximity to them during the smuggling days, when military escorts were common, and before highway robberies were put down. In later times, and before railways were introduced, these roads were much used for the transit of great herds of cattle to the southern markets.

Legislation, during that period, seems to have been a strong point in connection with road administration, as appears from the following:—"It is curious to refer to the progress made in turnpike legislation, which may be thus stated: from 1700 to 1710, twelve turnpike Acts were passed; from 1710 to 1720, twenty-one; from 1720 to 1730, seventy-one; from 1730 to 1740, thirty-one; from 1740 to 1750, twenty-nine; from 1750 to 1760, one hundred and eighty-five; from 1760 to 1770, one hundred and seventy-five; making, up to this period (seventy years), five hundred and thirty Acts of Parliament which had received the royal assent. These Acts were limited to a duration of twenty-one years, as it was presumed that at the end of that period the tolls imposed would not be required; the clerks of the several trusts always take care, however, that some creditors of the road should remain unpaid, by which means they contrive to keep the trust alive, and prevent their own office becoming extinct. The renewal of the Turnpike Act is also profitable to the clerk, and since 1830 the term has been prolonged to thirty-one years; at present (1847) the trusts in existence exceed 1100."*

With all this array of Acts for the making and maintaining of highways one may imagine that great improvements would have become general; this, however, does not appear to have been the case, at all events in the north of England, as the following will show:—

Mr. Arthur Young, in his *Six Months' Tour*, published in 1770, writes of some of the roads in the north of England:—"*To Wigan.* Turnpike—

* Cresy's *Encyclopædia of Civil Engineering*, 1847.

I know, in the whole range of language, no terms sufficiently expressive to describe this infernal road. Let me most seriously caution all travellers who may accidentally propose to travel this terrible country to avoid it as they would the devil, for a thousand to one they break their necks or their limbs by overthrows or breakings down. They will here meet with ruts, which I actually measured 4 feet deep, and floating with mud only from a wet summer; what, therefore, must it be after a winter? The only mending it receives is tumbling some loose stones, which serve no other purpose than jolting a carriage in the most intolerable manner. These are not merely opinions, but facts; for I actually passed three carts broken down in those eighteen miles of execrable memory." "*To Newcastle.* Turnpike—A more dreadful road cannot be imagined. I was obliged to hire two men at one place to support my chaise from overturning. Let me persuade all travellers to avoid this terrible country, which must either dislocate their bones with broken pavements, or bury them in muddy sand."

From the third report of the Parliamentary Committee on Turnpikes and Highways, 1809, it appears that a convexity of considerable elevation was generally adopted in repairing roads with a view

FIG. 4.—Cross-section of English road, about 1809.

to keep them dry. The convexity, approaching the form of a semicircle, was such that vehicles kept entirely to the centre of the road, the sides being dangerous; deep ruts were formed, which retained large quantities of water and mud, and in a short space of time the road became impassable, thus defeating the object for which it was constructed. Clods, rushes, soil, and all other materials, soft and hard, were thrown down in a promiscuous manner to give the convexity desired, this being surmounted with stones from old footpaths, with a small quantity of gravel raked over them to keep them together.

Fig. 4 shows a cross-section of an English road in 1809, the dark portion indicating the state of the road previous to being repaired as described above; the light shaded portion represents the appearance of the road after the repairs were carried out, and previous to the inspection by two magistrates on their way to the quarter sessions, who certified "that it was perfectly smooth when they saw it, and that a vast deal had been done since the last time they were there."

Great opposition was encountered as the extension of the turnpike system became general. Armed bodies of men assembled with the object

of destroying the turnpikes and burning down the toll-houses. So great was the contempt of the people for the new order of things, that in some districts they would not even use the new roads after they were constructed. The counties in which the greatest disaffection manifested itself were Yorkshire, Somersetshire, Gloucestershire, and many of the counties in Wales.

The carrying of the mails by stage-coaches and the ever increasing exchange of different commodities about the beginning of the present century, exercised the public mind as to the importance of having main roads constructed between distant centres of population and the coast. Enormous sums of money were spent in road construction between the years 1780 and 1830, during which time most of the turnpike roads in Scotland were made. They were for the most part well laid out and constructed, material of a suitable nature being abundant in most counties. The road proper, exclusive of the ditches and fences, had a minimum width of 20 feet, while many were made from 35 feet to 40 feet wide.

The intermittent and unsatisfactory manner in which road repairs were carried out in this country up to about the beginning of the present century appears to have been intolerable, and no real improvement was effected (although Metcalf made many new roads successfully) till the advent of Macadam and Telford. These two latter road-makers were contemporaneous and in some respects advocates of rival systems, and may be looked upon as the pioneers of good road construction. The methods adopted in effecting improvements and repairs were based on scientific principles, and the building of many bridges, where fords and ferries formerly existed, established a better means of communication between different parts of the country.

Metcalf.—John Metcalf was born at Knaresborough in 1717, and had the misfortune to lose his sight through illness, when about twenty-five years of age. After being successively a fiddler, soldier, horse-dealer, and carrier, he seems to have undertaken in 1765 a sub-contract for constructing a portion of the new road between Boroughbridge and Harrogate, extending to 3 miles, a trusty foreman carrying out his plans. As a road-maker his operations extended to Lancashire, Cheshire, Yorkshire, and Derbyshire, in which counties he constructed about 180 miles, involving in some instances the erection of many bridges, the building of retaining walls and culverts, and crossing difficult bogs in a successful manner. Metcalf died in 1810 at the age of ninety-two.

Macadam.—John Loudon Macadam was born at Ayr, in Scotland, in 1756, and educated at the parish school of Maybole. He passed his youth in the United States of America, but returned to Scotland at the close of the War of Independence (1783). Immediately thereafter he acted as a road trustee, was appointed manager of a district in Ayrshire,* and originated and successfully practised for many years the system of road making and

* Chambers's *Encyclopædia.*

repairing now known by his name. He held a government appointment from 1796, and resided in Falmouth and afterwards in Bristol, when, in 1815, he was appointed surveyor of roads in the latter town. It was in Bristol, where the roads extended to 178 miles, that he had full scope for putting into practice the great improvements in road making which had occupied his thoughts, and which he had successfully carried out when in charge of the Ayrshire roads many years previously. This was "to put broken stone upon a road, which shall unite by its own angles so as to form a solid hard surface." "It follows," he adds, "that when that material is laid upon the road it must remain in the situation in which it is placed without ever being moved again, and what I find fault with in putting quantities of gravel on the road is that, before it becomes useful it must move its situation and be in constant motion." * The distinctive novelty of Macadam's system, the value of which has been established by universal experience, was to substitute small angular stones, prepared from larger pieces, for the large rounded stones then generally made use of in road repairs.

Macadam's system of construction was simply to spread broken stones, 2 inches in diameter, equally, so as to form a layer about 10 inches thick over the road surface, after it has been levelled and properly drained where necessary. The convexity given was just sufficient to cause the rain-water to run readily off the surface into the side channels.

Macadam found the roads in the Bristol district loaded with material of large and irregular size, to the extent of from 2 to 3 feet in thickness. This great amount of rough material (limestone) he utilized by lifting or excavating the whole mass, separating it from the mud, and breaking the stones to a uniform size of 6 oz. in weight. The formation of the road was then properly levelled, and drainage introduced where necessary, the metal prepared from the rough material being carefully relaid, and regularly raked during the process of consolidation by the carriages passing over it. The surface of the roads was kept even and clean by the addition of proper fresh materials, when necessary, distributed equally in thin layers immediately after rain, in order that the new materials might bind and incorporate properly with the old. Macadam strongly condemned the use of binding material for filling up the interstices in the metal, which he left to work in and unite by its own angles by means of the traffic. He says "that every road is to be made of broken stones, without mixture of earth, clay, chalk, or any other matter that will imbibe water and be affected by frost."

When reconstructing or repairing a road, Macadam endeavoured to have the whole of the material composing it higher than the surface of the adjacent ground, so as to give every facility for the water to escape from the bottom as well as from the surface of the road. The size of metal adopted

* *Report of the Select Committee on the Highways of the Kingdom*, 1819, p. 22.

by Macadam was that of a cube of 1½ inch; he preferred, however, to specify the weight of the stone, and insisted that it should not weigh more than 6 oz.

His system of maintaining the surface of a road was found so beneficial that he was engaged as general surveyor by many of the road trusts in England and Scotland. By his business-like and extended views on road administration, he not only reduced the debt and placed the finances of the many trusts on a sound basis, but established for himself a world-wide reputation.

In 1824 the Road Trustees of the Carse of Gowrie Turnpike Road (Perthshire), between Perth and Dundee, consulted Macadam as to the repairs on this highway, which was gradually falling into a state of such great deterioration that travelling over it was disagreeable, while the Trustees had been threatened with a prosecution at the instance of the Postmaster-General on account of the delay occasioned to the mail coaches. The Trustees considered the annual expenditure for the maintenance of this road beyond what they deemed necessary under the circumstances. From the correspondence which took place between the Road Trustees and Macadam, it would appear that the prevailing practice in Scotland and many districts in England, when forming new roads, was to excavate a trench or metal box in which the stones were placed; in other words, the material was deposited below the natural surface of the ground, so that a mound of earth was raised on either side of the metal bed. The subsoil in this part of the country through which the turnpike road passed being of retentive clay, Macadam decided to lift the existing road, and thoroughly drain the road bed. He also found it necessary to break the large stones, some of which were 9 inches in diameter, to a regular size, and relay the metalling carefully, any deficiency in quantity being made good with a supply of fresh materials. The result of these improvements was a thoroughly serviceable road, and the expressions of gratitude conveyed to Macadam by the Carse of Gowrie Road Trustees is a clear proof of the great benefit arising from the system adopted in repairing their roads; the saving effected in the maintenance placed the funds of the Trust in a sound financial position. It may be interesting to note that, at the time when Macadam was engaged by so many road trusts, he had a staff of 300 sub-surveyors under his charge. In 1827 he acted as General Manager of the Metropolitan Roads. The system advocated by Macadam was so popular at one time that expensively paved streets, such as that between Edinburgh and Leith, were torn up to be remade by the new process. On streets having an excessively heavy traffic, Macadam's system of construction has no place, and Dublin is instanced as a failure of his method of road repairs.

It is said that Macadam was anticipated in his system of a regularly

broken stone covering by Mr. Edgeworth, an Irish proprietor, whose system was advocated in *An Essay on the Construction of Roads and Carriages*, a second edition of which was published in 1817. An article which appeared in the *Westminster Review* in 1825 states that "The name of Mr. Macadam deserves a few remarks for other reasons than its present popularity. The public naturally took to him as a sort of magician, and his invention, as it is thought, as something preternatural."

"If his own name had not been macadamizable into a verb, it is probable that his roads would have been little known. He did not invent the method in question of breaking stones, because it had long been the practice of Sweden, Switzerland, and other countries, and was long known to every observing traveller."*

In view of what has been stated, it seems curious that the road engineers in France, where the highways were considered, at the beginning of this century, to be superior to any in Europe, should not have adopted the system which it is said prevailed in the countries mentioned, in preference to Macadam's method, which was practised between 1820 and 1830 and officially adopted in that country at the latter date.

It may be further mentioned that the system promulgated by Macadam was practised by him in Ayrshire at least thirty years previous to the appearance of Edgeworth's essay or the article referred to in the *Westminister Review.*

It is considered by all impartial observers that Macadam was the pioneer of good road construction and administration, and by his practical abilities was entitled to the reputation of a public benefactor. He died at Moffat in 1836 at the age of 80 years.

Telford.—Thomas Telford was born in the district of Eskdale, in the county of Dumfries, on the 9th of August 1757, and obtained the rudiments of his education in the parish school of Westerkirk. Learning the trade of a mason, he subsequently studied architecture in Edinburgh, and latterly in London, and being a man of ability he soon established himself as a leading engineer.

Bridge building was his great forte, but he carried out many other engineering works, particularly that of laying out and constructing new roads in all parts of the kingdom. He held the appointment of Surveyor of Public Works in Shropshire subsequent to the year 1787, and in that capacity he erected many fine bridges over the Severn.

His first undertaking as a road-maker on an extensive scale was in the Highlands of Scotland, whither he was sent by the Government in 1802 to report as to the best means of developing the resources of the country.

* *The Westminster Review*, vol. iv. (July, October) p. 354. "The Commercial Power of Britain." By the Baron Dupui, etc. Translated from the French. C. Knight, London, 1825.

He advised the opening out of the country by a complete system of roads, so as to bring the interior parts into communication with the towns and the coast.

Under his direction, and by the aid of Parliamentary grants, amounting to £450,000, roads extending to 920 miles were laid out and constructed, and owing to the hilly and rugged nature of the country, works of considerable magnitude had to be undertaken, including 1117 bridges. This work was carried out in the course of eighteen years, under 120 contracts, and without recourse being had to a court of law in any one instance.

The following specification, drawn up by Telford and referring to the construction of the Highland Roads, is given in detail, having a peculiar interest, especially at the present time, in so far as it refers to one of the largest pieces of road making undertaken at any time in this country.

General Specification for the Highland Roads.

"The road to be formed to the full breadth of 20 feet in the clear, including the side drain and green margin, except on places where there is an absolute necessity for cutting the whole breadth of the road in solid rock; and in those places the breadth of the road shall be 18 in the clear, between the parapets which may be necessary for a safeguard, and those parapets are to be 2 feet in thickness at the bottom, so that in rock the cutting will be 20 feet in breadth, and in all cases the road is to be so laid out, that there shall be no quick bendings, nor its upper side interrupted by points of rock.

"On dry bottomed ground, gravel of a proper quality, out of which all stones, above the size of a hen's egg, shall have been previously taken, shall be laid to a depth of 14 inches in the middle, and 9 inches at the sides; but the stones which are taken out of the gravel, and do not exceed 4 inches in size, may be laid for that thickness below the gravel, and in that case 10 inches only of cleansed gravel will be required.

"On mossy ground or swampy soils, if the moss or soft matter is not more than 2 feet in thickness, and a hard bottom below this moss or soft matter, it is to be wholly removed, and the road formed on the harder substance as above described; but when the moss or soft matter is more than 2 feet in depth, the contractors are to have their option of either removing it, or forming the road upon the top of it in the following manner.

"Where the surface is level, and covered with sound sward or heath, there must be laid two rows of swarded turf, with the swarded side of the one downwards and of the other, which is to receive the gravel, upwards; or otherwise, where turf cannot be readily procured, the surface of the moss or soft matter may be covered with a layer of brushwood or heath, which, when compressed, shall not be less than 6 inches in thickness; upon the

surface so compressed and prepared, there shall be laid gravel, cleaned as before described, to the thickness of 18 inches in the middle and 13 inches at the sides.

"In all cases, whatever be the nature of the soil, the road is on all the flat ground to be brought to a perfect level from side to side, before the gravel is laid on; but in all cases where the road is to be raised on the one side by moved ground, while the upper side is on the natural ground, the lower side of the road, when finished, is to be from 4 to 6 inches higher than the upper side, in proportion to the quantity of moved ground on the lower side.

"In side cuttings in steep banks, even if there is no moved ground on the lower side, still the lower surface of the finished road is to be on at least 4 inches higher level than the upper side. Where the ground is level or flat, the road is to be gravelled to 18 feet in width, and to have a border of green turf on each side, 1 foot in width.

"When the road is formed on a sloping bank, where no parapets are necessary, there is to be a border of green turf on the lower side of the road, 1 foot in breadth in the clear.

"The drains are to be formed perfectly regular, and so as the course of the water shall not be interrupted by points of rocks or sudden turnings; and where the soil is soft and loose, these drains on the upper side of the road are to be paved with small stones, not less than 4 inches in depth. These pavements are to be made at the places pointed out by the inspector; they are to be carried to the extent, and made in the shape, he shall direct.

"Where the parapets are necessary, the road is to be gravelled to the breadth of 18 feet as before described. And also the said contractors bind themselves and their foresaids to make in a sufficient manner all back drains, of such dimensions, and in such directions, as shall be necessary for effectually collecting and conducting the water in a proper manner from the higher grounds to the nearest bridges or covered drains, especially where the road is formed along steep and sloping banks, and the ground is wet and swampy, and that at the places which shall be pointed out by the said surveyor, so that the road shall always be kept free from water.

"Where the road is to be formed upon level ground, and particularly where it is mossy and swampy, side drains are to be made of sufficient depth to drain the ground, and in all cases quite sufficient to carry off the water. These side drains to be made with a slope from the road to within 1 foot of the further side of the drain, so that if the depth at the further side be 30 inches, the width at top shall be 6 feet, and so more or less in proportion to the depth, and which side drains shall be made at the places approved of by the surveyors: and also to make covered drains of dry stones at all places where necessary; the inside walls of these drains are not to be less than 2 feet in thickness, and the stones for that length to be laid regular: these covered drains shall in no instance (without particular directions in

writing from the principal engineer employed by the Commissioners) be less than 2 feet square; they are to be properly secured in the bottom by paving with stones set on edge; the pavement as well as the sides are to be secured at both ends of the drains by stone work, so that it shall appear evident there is no risk that they shall be injured by the water, where it enters into or issues from the drain. The stones with which the 2 feet drains are covered are to be not less than 3 feet in length and 4 inches in thickness, and laid so close together on stones of equal length overlapping each joint, as shall effectually prevent the gravel from passing down into the drain, and leaving a hole in the road. But in case it shall be discovered during the execution of the road that, instead of some of the 2 feet, the road may be better protected by making a greater number of drains of smaller dimensions, the contractors, upon receiving instructions in writing from the principal engineer, shall execute them in such a manner, and counting two drains of 18 inches, or three drains of 12 inches, in lieu of one drain 2 feet square, and in case of drains of 18 inches being made, the stones of the covers shall not be less than 30 inches in length; if 12 inches, the covers to be 2 feet in length; and in order to secure the due execution of the said covered drains, it is expressly declared that the same shall be subjected to the inspection and approval of the resident surveyor before the covers are laid on, that he may be satisfied that the bottoms are properly paved, and the sides are built in a sufficient manner; and after the said drains are covered, the backs of the buildings are to be made up with stones to the level of the upper beds of the covers, and the said drains shall be constructed so that they shall have a sufficient covering of gravel, not exceeding 12 inches, to the satisfaction of the surveyor, without causing any swell on the road. And also the said contractors bind and oblige themselves, and their foresaids, to build and erect breastworks of stone at all places where necessary on the lower side of the road, along the side of water-courses, or on sloping banks, or on rocks; the foundation of the said breastwork must be cut into the rock or solid ground for the whole breadth of the base of the wall or breastwork which is to be placed on it, as hereafter described, and its direction is to be dipping into the hill at a right angle with the slope of the face of the breastwork. If it shall be necessary to make the breastwork 3 feet in height, from the foundation to the level of the lower side of the road, the breadth of the foundation shall be 24 inches, and 18 inches at the top, or level of the lower side of the road. If the height is 4 feet, the breadth of the foundation is to be 30 inches, and at the top 24 inches. If the height is 6 feet, the breadth at the foundation is to be 3 feet, and 2 feet at the top. If the height is 8 feet, the breadth of the foundation is to be 4 feet, and at the top 2 feet, and so on in proportion to any greater or lesser height. In forming these breastworks,

the stones are to be laid in regular manner, quite through the thickness here described; the slope which is necessary to bring the wall to its thickness at the top is all to be taken off the outside, and the stones are to be laid mostly lengthwise into the wall; the space behind the breastwork and natural ground, up to the level of the top of the formed roadway, is to be filled up with coarse gravel or stones (neither sand, sods, nor moss to be used), and if with stones they are to be covered and brought to the levels formerly described, with a layer of strong swarded turf, before the cleansed gravel is laid on.

"At all times, when the nature of the cutting makes it possible, the resident overseer shall have an opportunity of examining the breastwork when completed, before the inner side shall be filled up with stones or gravel as aforesaid; and also, where it shall be necessary for the due execution of the said road, to erect parapet walls above breastworks, or upon rock, they are to be built with stones laid in good lime mortar, agreeably to the ground report.

"These parapets are to be 2 feet wide at the foundation, and 18 inches at the top. The height above the finished roadway is to be 2 feet 9 inches, including a coping of stones 9 inches deep. These coping stones are to be chosen so as to meet one another in close regular beds or upright joints, to be firmly wedged together, and pointed with lime mortar.

"At each extremity of the parapets the copings are to be well secured with the ends turned down under the roadway, and also where it shall be necessary in forming the road, to cut and remove earth from the higher side, to the depth of 2 feet or more, the road must be formed 21 feet 6 inches wide, and, to prevent the earth from falling into the drain on the upper side of the road, a wall of dry stones must be erected of a height according to the depth of the cut. The foundation of these retaining walls is to be laid in all cases 6 inches below the bottom of the drain, on the upper side of the road: there the thickness is to be from 15 to 18 inches to the height of 4 feet; above that height, they are to be one-third of the thickness. The stones with which they are to be constructed are to be laid in a regular and workmanlike manner for the whole thickness of the wall: they are to be carried to such a height, that the slope from them to the solid ground of the bank above is not to be less than two horizontal to one perpendicular, and that slope to be covered with turf laid flat.

"And further, the contractors are to be bound to cut down all heights, fill up all hollows, and blast all rocks upon the said line of roads, as pointed out by the said reports, and which shall be requisite and necessary for the same: and further, the said line of road shall be formed and prepared for the gravel for one mile at least per advance to the satisfaction of the surveyor employed by the said commissioners before any of the cleansed gravel is laid on." *

* Cresy's *Encyclopædia of Civil Engineering*, 1847.

Where the ground on which the road materials were to be spread was of a soft nature, a concrete foundation composed of lime and gravel or hard stone, and varying in thickness from 6 inches to 12 inches, was spread over the entire surface, and broken stones laid on before the concrete became set, so that it might bed itself and become firmly united with it.

Telford, in 1816, directed the works in connection with the improving of the road between Glasgow and Carlisle, the old road having become impassable. The improvement and reconstruction of this road were undertaken as a work of national importance, and £50,000 were granted by Parliament with this object. The method of constructing this road differed materially from those carried out in the Highlands, as it was necessary to provide for the transit of the mail and heavy coaches, the gradients being made easy, not exceeding 1 in 30. The old road was in length 102 miles; the existing one is not more than 93, and in order to gain this nine miles it was necessary to reconstruct 69 miles entirely, and to build fifteen new bridges, excluding which the cost of the road making was about £1000 per mile. It was specified "that the breadth was to be 34 feet between the fences, 18 of which were to be metalled, and the remaining 8 feet on each side to be covered with gravel. In all embankments the width on the top to be 30 feet, and the side slopes 1½ horizontal to 1 perpendicular; in all cuttings above 5 feet the width between the lower skirts of the slopes 30 feet, all below that depth to be 34 feet. The slopes of all the cuttings to be at the same rates as the embankments.

"The surface of the road longitudinally, or lengthwise, in all cases where there were cuttings and embankments, to be formed as shown, and in no instances the ascents or descents to exceed 1 in 30, and the changes from one to the other to be made in regular curves, to the satisfaction of the inspector.

"Where there were side cuttings, and a part of the road made on moved ground, the surface of the lower part or moved ground to be higher than that of the upper side to allow for consolidation, so that when finished it might have the proper level. In the middle of the road a metal bed to be formed, and in all cases where the ground was nearly level, the metal to be laid upon the natural surface of the ground, so as to have a curvature of 4 inches, in the middle 18 feet, and the sides or shouldering to be made with moved ground, but on no account is the metal bed to be cut out of the natural ground, unless that be loose gravel or rock.

"The metalling to consist of two beds or layers, viz., a bottom course of stones, each 7 inches in depth, to be carefully set by hand, with broadest end downwards, all cross bonded or jointed, and no stone to be more than 3 inches wide on the top. These stones to be either good whinstone, limestone, or hard freestone; the vacuities between to be carefully filled with smaller stones packed by hand, so as to bring the whole to an even and firm surface.

"The top course or bed to be 7 inches in depth, to consist of properly broken stones, none to exceed 6 ounces in weight, and each to pass through a circular ring 2½ inches in diameter in their largest dimension. These to be of hard whinstone, the quality of both bottom and top metal to be determined by the inspector. In every 100 yards in length on each side of the road, upon an average, there was to be a small drain from the bed of the bottom layer to the outside ditch, as directed by the inspector. When the height of the embankments exceeded 3 feet, they were to stand from one to three months, in proportion as they increased in depth, as determined by the inspector. Over the upper bed or course of metal to be a binding of gravel of 1 inch in thickness upon an average; the cross-section of the finished roadway to have a curvature of 6 inches; in the middle 18 feet, and from that on each side a declivity at the rate of half an inch in a foot, to within 18 inches of the fences; the remaining space of 18 inches to have a curvature of 3 inches, making in all about 9 inches on each side below the finished roadway.

"In passing morassy ground all the surface upon which the road is to be placed, viz., between the fences, to be brought to a curvature of 12 inches in the middle, and to be secured with two rows of good swarded turf, the lower end to be laid with the swarded side downwards, and the upper one with it upwards. The metalling upon the said mossy ground to be made 20 feet in width; a drain to be cut alongside of the road, 4 feet wide at the top, 18 inches at the bottom, and 3 feet deep.

"*Cross Drains.*—Nine to be made in every mile in length, placed in situations marked out by the inspectors; 18 inches wide, 16 inches high at the upper end, and 22 inches high at the lower end; their bottoms to be paved with flat or small pebble stones, 4 inches in depth. The foundations of the side walls to be laid at least 6 inches below the level of the bottom of the drain, and these not to be less than 18 inches in thickness, laid in regular courses, faced on both sides in the manner of a good stone dyke. The top of each to be properly levelled, and covered with a firm turf 2 inches in thickness to form a bed for the covers. The covers to be 2 feet 6 inches in length and 4 inches in thickness; their side joints to be made straight, so as to unite closely, the parts which lie on the turf to be flat.

"These drains must be of a length not only to cross the road, but the fences on each side, also the slopes of the embankments, and pass fairly into the fields or natural water-courses; from the ends of the drain, wing walls to be extended 5 feet in a curved direction into the solid ground, these to be of the same thickness as the side walls, founded at the same depth, and carried to the same height, and coped with two rows of swarded turf. The bottom between the wing walls to be paved with stones not less than 6 inches in depth, and well secured at the extremities by stones 12 inches in depth, and these to be well secured at the upper ends, and connected with the firm ground and side drains. The whole body of the drain

to be of such a depth as to admit of a turf being laid over the covers, and the full quantity of road metal and binding, without raising the longitudinal line of road. At each end of the cross drains, the water which passes along the side of the road to be introduced by a proper opening, protected by a stone cover; this entrance to be paved at least 5 feet in length. In passing through morassy ground, the bottom of the drains to be laid with flat stones quite across, and at least 12 inches under each side wall, to be continued quite to the extremity of the wing walls.

"To keep this road in repair after it was made required at the least 80 cube yards of broken stone per mile, and at the most 120 per annum; the cost of which varied from £20 to £46 per mile." *

Fig. 5 is a cross-section of the Glasgow and Carlisle Road, showing *cross* and *surface* water drains.

From Scotland Telford extended his operations to England and Wales, where the roads, which had been laid out some years previously, were in such a condition as to require to be reconstructed. The Government in 1815 engaged Telford to make the Shrewsbury and Holyhead Road—one

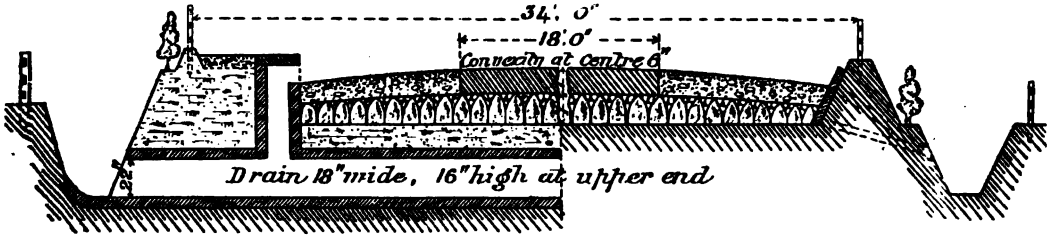


FIG. 5.—Cross-section of road showing cross and surface water-drains.

of the finest pieces of road-engineering carried out up to that time in the world, and the Menai and Conway bridges in connection with it. This road was considered, owing to its lying in the direct line of communication between England and Ireland, of sufficient importance to be deemed a National undertaking. Its condition, along with the portion to London, was reported on annually by Telford till his death.

The construction of this road is practically similar to that of the Glasgow and Carlisle road, a cross-section of a 30 feet roadway being shown at fig. 6.

Such were the great improvements effected by Telford in carrying out these works, that the Select Committee of the House of Commons in reporting on the matter, stated as follows:—

"The professional execution of the new works upon this road greatly surpasses anything of the same kind in these countries.

"The science which has been displayed in giving the general line of the road a proper inclination through a country whose whole surface consists of

* Cresy's *Encyclopædia of Civil Engineering*, 1847.

a succession of rocks, bogs, ravines, rivers, and precipices reflects the greatest credit upon the engineer who has planned them; but perhaps a still greater degree of professional skill has been shown in the construction, or rather the building of the road itself. The great attention Mr. Telford has bestowed to give to the surface of the road one uniform and moderately convex shape, free from the smallest inequality throughout its whole breadth, the numerous land drains, and, where necessary, sewers and tunnels of substantial masonry with which all the water arising from springs or falling in rain is instantly carried off; the great care with which a sufficient foundation is established for the road, and the quality, solidity, and disposition of the materials that are put upon it, are matters quite new in the system of road making in these countries." *

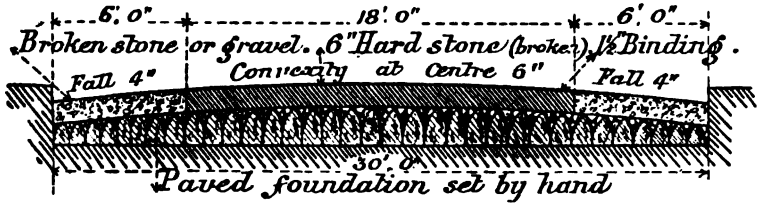


FIG. 6.—Cross-section of Shrewsbury and Holyhead Road—Telford.

The following rules were prepared by Telford in 1820, as instructions to those in charge for the proper maintenance of the road between London and Shrewsbury, at the instance of the Parliamentary Commissioners:—

GENERAL RULES FOR REPAIRING ROADS.

I. SHAPE OR CROSS-SECTION.

Rule 1.—Upon a road of 30 feet in width, the sides should be 9 † inches below the surface of the middle. The best line of the cross-section is a segment of a flat ellipse. This shape not only assists the water to pass from the centre towards the sides, but contributes to the drying of the road by allowing the action of the sun and air to produce a great degree of evaporation. Surveyors ought to use a level in giving roads a proper shape, in order that the surface may be of one uniform curvature, without the smallest deviation in any one spot from the prescribed line of the cross-section.

II. DRAINAGE.

Rule 2.—All ditches ought to be on the field side of the road fences, and to be connected with the natural water-courses of the country.

* *Report from the Select Committee on the Road from London to Holyhead in the year 1819.*

† Telford afterwards considered 6 inches sufficient for this width.

The stone cross drains and culverts which pass under the road should be numerous, and continued through under the fences into the ditches.

In order to keep a road perfectly dry, openings of mason-work should be made from the side drains of the road into all these cross drains, to carry off the water collected from the surface of it. The bottom of these cross drains must be well paved, particularly at these openings.

It ought never to be forgotten that in order to have the surface of a road perfect, it must be kept completely dry.

All land springs ought to be carried from the side of the road by under-draining.

III. TREES AND FENCES.

Rule 3.—It is absolutely necessary to remove trees from the sides of roads, and to keep the fences under 5 feet in height. Not less than 20 per cent. of the expense of repairing roads is incurred by the trees and the improper state of the fences keeping the roads wet, and by that means occasioning the rapid destruction of the materials.

IV. MATERIALS.

Rule 4.—Where the materials are quarry or field stones, the hardest part of them should only be used. Each stone should be so broken that it may, in its largest dimension, pass through a ring $2\frac{1}{2}$ inches in diameter. Hammers with slender handles, light and well-steeled, must be made on purpose for breaking them. This work ought always to be done by measure, either at the quarries or in proper recesses made for the purpose on the sides of the road. Men who are past hard labour, and women and boys may be employed on it.

Rule 5.—Where the materials consist of gravel, the stones only which exceed $1\frac{1}{2}$ inch in size should be taken from the pits for the repairing of the middle part of the road, of 18 feet in breadth. These ought to be raked together as the gravel is thrown up by the workmen. This process will, in most cases, save the expense of riddling and washing the gravel. The small gravel and gravelly portions of the pit may be used for the sides of the roads and the footpaths. Every gravel stone which exceeds $1\frac{1}{2}$ inch in size ought to be properly broken, either in the pits or in the aforesaid recesses. A pronged shovel should be used in putting the stones into the barrows. Surveyors should pay very particular attention to this rule, because the common use of a mixture of round gravel and clay is a public nuisance, and must be got rid of. When a surveyor obstinately persists in this practice, the trustees should dismiss him.

V. DISPOSITION OF MATERIALS.

Rule 6.—Where a road has no solid and dry foundation, it must be constructed anew. It must be well drained, and put into a proper form. Upon

the 18 centre feet of it stones must be put, forming a layer 7 inches deep. Soft stones will answer, or cinders, particularly where sand is prevalent. These bottoming stones must be carefully set by hand, with the broadest end down, in the form of a close, neat pavement; the cavities should be filled with stone chips to make all level and firm, and no stone should be more than 5 inches broad on its face. This proportion of a solid and level foundation is the most essential point to be secured in order to have a perfect road, and that the draught of carriages may be eased as much as possible. Over this bottoming of stones or cinders, 6 inches of stones, of a proper quality, broken to a size that will, in their largest dimensions, pass through a ring of 2½ inches diameter, must be laid. The 6 feet of the road on each side of the 18 centre feet (making 30 feet), when formed of a proper shape, may be covered with 6 inches of good clean gravel or small stone chips.

Where a road has some foundation, but an imperfect one, or is hollow in the middle, all the large stones appearing on the surface of it must be raised and broken; the 18 centre feet of it must then be covered with a coating of broken stones, sufficient to give it a proper shape, and to form a bed of solid materials of at least 13 inches in depth, to make it solid and hard.

Where a road already has a good foundation and also a good shape, no materials should be laid upon it but in thin layers, for the purpose of filling ruts and hollow places as soon as they appear. Stones broken small, as above described, being angular, will fasten together. In this way a road, when once well made, may be preserved in constant repair at a small expense.

Where the breadth of that part of a road which alone has been formed of hard materials, and over which the carriages commonly pass, is less than 18 feet, it must be widened with layers of broken stones to that breadth, first digging away the earth and forming a bed for them with pavement and broken stones, at least 10 inches deep. Near large towns the whole breadth of the roadway should be covered with broken stones.

VI. MANAGEMENT OF LABOUR.

Rule 7.—All labour by day's wages ought, as far as possible, to be discontinued. The surveyors should make out specifications of the work of every kind that is to be performed in a given time. This should be let to contractors, and the surveyors should take care to see it completed according to the specifications before it is paid for. Attention to this rule is most essential, as in many cases not less than two-thirds of the money usually expended by day labour is wasted.

In all probability the contract system was introduced with a view to get rid of the paupers then employed on the Holyhead road, as Telford afterwards, in 1819, on some portions of this road, at least, placed foremen in charge of 4 to 6 miles of road, having under them a

sufficient number of labourers to keep the road in proper shape. Further, in 1823, he says that "a certain number of labourers ought always to have the care of the surface of the road, and never quit it for a single day to do anything else; they will always have sufficient to do in spreading materials in ruts and hollows, in scraping the road, in cleaning out the side channels and keeping open the water-courses, and generally in maintaining the road in a clean and sound state. A few men constantly so employed will do a great deal towards the preservation of a road, while the greater number of workmen should be as constantly employed in providing materials by contract work."

It is noticeable, however, that in the Highlands of Scotland and in Wales, where the population was sparse and labour difficult to obtain, that he invariably adopted the contract system of maintaining the roads.

Telford, in 1830, supplemented these foregoing general rules by the following specification:—

SPECIFICATION for the regulation of the surface between the fences, so as to establish uniformity in the cross-section.

1. The road is to be 30 feet wide, with a fall of 6 inches from the centre to the side channels, but exclusive of the footpaths.
2. Two sods to be laid on each side of the road, one upon the other; the lower one 12 inches wide, the upper 8 inches, and each 4½ inches in thickness; and in such manner as to form curved edges when they grow together; the top surface of the sods on each side to be exactly on the same level.
3. On one side of the road a footpath to be made behind the sod; it is to have an inclined surface of 1 inch in a yard towards the road; and another sod to be laid along the outer edge of the footpath, 8 inches wide, on a level with the footpath.
4. On the other side of the road a flat mound of earth to be formed behind the sods, on a level with the top of them, 5 feet 8 inches wide; the surface of this mound to be made with sods or sown with grass seeds.
5. The waste land, where there is any, on each side between the footpaths or the mound and the road fences, to be dug over in the breadth of 4 feet, at right angles to the fences, and made quite smooth; when these wastes are covered with grass, the sod to be pared off each breadth and laid on the breadth last dug; when they are not in grass, the new surface is to be sown with hay seed.
6. If there is a ditch on the roadside of the fence, or if the road fence consists of a high bank, a new post and rail fence is to be made close along the footpath and mound, with a ditch on the field side at least 3 feet deep.

An instance of what can be done by proper engineering in the laying out of a new road, or improving the gradients of an existing line of communication, may be gathered from the following facts of a case in which Telford's skill as an engineer may be cited. An old road in the island of Anglesea, 24 miles in length, so undulated that a horse ascended and descended 1283 feet of vertical height more than was found necessary by the new line of road, and the distance was shortened by $2\frac{1}{3}$ miles. Another instance of what could be done in relieving the public of unnecessary and avoidable ascents, and which add greatly to the tractive power entailed, may be mentioned. On the road from London to Barnet the rise or number of perpendicular feet which a horse must now ascend is upwards of 1300, although Barnet is only 500 feet higher than London; and *vice versa*, a horse must ascend 800 feet, although London is 500 feet lower than Barnet.

The introduction of railways in this country had a disastrous effect on the turnpike system of collecting revenue, the traffic, mainly passenger, being diverted to the more expeditious and economical means of locomotion. This particularly applied to roads which connected large towns, and after the completion of the railway system, running in many cases parallel to these roads, the decreased revenue caused by the diverted traffic and revenue was of an almost revolutionary nature, thousands of stage-coaches being thrown out of employment. Many main roads became of little importance; but those, including statute labour roads, running at an angle with the railways, connecting the districts on either side, became the great feeders in the exchange of products, and for the most part require in modern times the most attention. It is not to be wondered at, therefore, that, as the railways grew in favour, the revenue of the 'turnpikes' became gradually less each year. This change in the course of events was anticipated by many before railway communication was an accomplished fact, and methods were proposed to meet the change of circumstances which would necessarily be entailed.

It was not, however, till many years after the new mode of travelling came into existence that county authorities saw the necessity for a change in the turnpike system, so as to obtain a revenue for the proper maintenance of the roads.

In 1865 and following years 'local Acts' were obtained, abolishing tolls in certain counties in Scotland, and in 1878 there was passed for this purpose a general permissive Act, which was to be compulsory after 1883, under which all roads are classified as highways.

The method of raising revenue under the old system of statute labour, generally commuted and paid for as plough gates, etc., and tolls administered by a great many trusts, with no view in common, seems to have been a very cumbrous piece of machinery. The management, apart from that

of maintaining the roads, cost considerable sums in the form of profit to the tacksman, amounting in some cases, it is said, to over £9 per mile. It is very evident that this profit, in addition to the expense of repairing the toll-houses, gates, etc., formed a sum which, had it been applied direct to the maintenance of the roads, would have been sufficient to keep them in excellent condition.

The disputes arising between the collectors, the public who used the roads, and the trustees, were numerous, litigation in a perpetual form being the order of the day.

This, no doubt, was a weak spot in the turnpike system, which, combined with the introduction of railways and consequently reduced revenues, was mainly instrumental in bringing about a new order of things.

The present system of raising the necessary revenue for road purposes, viz., by assessment on rental, one half being payable by the proprietor, the other half by the occupier, appears to answer well, although those not using the highways directly consider themselves aggrieved. As, however, all articles of consumption pass over the roads, the ratepayer is saved indirectly in the purchase of all such commodities.

The extended powers for the further improvements of highways conferred on County Councils by the "Local Government Acts" (England 1888, Scotland 1889) admit of the different counties and districts thereof concentrating the management in a uniform and intelligent manner.

By these means plant for the repairing of the roads can be purchased, such as rock drills, stone-breaking machines, steam rollers, and many other appliances. Greater efficiency is, therefore, now possible by their proper application, while economy in carrying on the work of maintenance is promoted by judicious management.

PART I.

CHAPTER I.

RESISTANCE TO TRACTION—WHEELS AND WEIGHTS ON THEM.

PREVIOUS to entering upon the subject proper of road construction, it will be necessary to notice briefly the effects of the resistance to traction on a road surface, and the points to be considered in determining the ruling gradient which should be adopted on a proposed road, according to the situation, and the class of traffic likely to pass over it.

The main external forces which offer resistance to the motion of vehicles upon roads are:—Friction, collision, gravity, and air resistance.

1. External Forces affecting the Motion of Vehicles.—(1) *Friction.*—This arises from the rolling resistance of the wheel tires when in contact with the surface of the road. It involves the consumption of part of the force exerted by the prime mover. Under friction may be considered the resistance of penetration, which is brought about by a yielding road surface, that is, a weak and inferior road, or one on which gravel or loose stones have been spread, also on soft earth. In these circumstances the resistance to traction is less the larger the diameter of the wheels, as larger wheels sink less and spread along a greater surface than wheels of less diameter; the areas of immersion, however, are equal in either case.

Resistance arising from the friction of the axles is nearly constant at all velocities, and may be neglected. It may, however, be mentioned that with wheels of ordinary construction the resistance amounts to from $\frac{1}{130}$ to $\frac{1}{100}$ of the weight on the axle, or 17 to 22 lbs. to a ton of load. Friction of the wheel on its axle is independent of the condition of the surface of a road.

(2) *Collision.*—This may be caused by the want of uniformity or irregular condition of the surface of a road, or may be occasioned by hard substances, such as loose stones, which give a sudden check to the forward movement of vehicles. Considerable injury is done to a road surface by a vehicle surmounting any hard substance, and the wheels descending with great force tend, by repeated blows, to wear holes in the surface, even on roads maintained with the hardest material. By the carriage being

mounted on springs, the power required to draw a vehicle over an obstacle of this kind is lessened, and the damage to the surface of the road is also greatly reduced.

(3) *Gravity.*—When a road is on an incline, the additional influence due to gravity, which is proportionate to the steepness of the gradient, must be allowed for in arriving at the greatest tractive force which the prime mover is capable of exerting. The resistance due to gravity on an incline is found approximately by dividing the number of pounds in a ton by the rate of inclination.

(4) *Air Resistance.*—This varies according to the velocity of the wind, the area of the surface acted upon, the velocity of the vehicle, and the angle or direction at which it impinges against the plane of the surface. At a velocity of 15 miles an hour, equivalent to a pleasant breeze, the force of the wind is equal to 1·107 lbs. per square foot, while at a velocity of 50 miles an hour, amounting to a violent storm, the force is equal to 12·30 lbs. per square foot of surface.

2. Tractive Force.—The power required to move vehicles along a road depends on, and varies greatly according to, the condition of the surface of the road. The force or pull which a horse has to exert to draw a load on a level macadamized road in ordinary repair may be taken at $\frac{1}{30}$ of the load, but may vary from $\frac{1}{48}$ of the load on roads in the best condition to $\frac{1}{25}$ on roads the surface of which is badly maintained, and broken by ruts and hollows.

Authorities, however, differ widely on the subject of the tractive power of the horse, and this will be obvious when the varying diameters of wheels of vehicles and the strength and speed of different animals are taken into consideration, along with their adaptability or training for any particular class of work.

TABLE I.

Materials.	Resistance to Traction on Level.	Tractive Force in lbs. required to move one ton on a Level. A.
Asphalted roadway,	1·0	15
Paved roadway, dry and in good order,	1·5 to 2·00	22·5 to 30·0
,, ,, in fair order,	2·0 to 2·5	30·0 to 37·5
,, ,, but covered with mud.	2·0 to 2·7	30·0 to 40·5
Macadamized roadway, dry and in good order,	2·5 to 3·0	37·5 to 45·0
,, ,, in a wet state,	3·3	49·5
,, ,, in fair order,	4·5	67·5
,, ,, but covered with mud,	5·5	82·5
,, ,, covered with loose stones,	5·0 to 8·2	75·0 to 123·0

The figures in Table I. are now generally adopted in arriving at the relative tractive force necessary to draw a load on different kinds of

material composing a road surface.* Asphalte is taken as the standard of excellence, and in the extended part of table, under A, 15 lbs. is allowed for the force necessary to draw one ton on a level on that class of road.

On a macadamized road maintained in excellent order the table shows that the force put forth by the prime mover is 45 lbs. per ton, or a tractive force exerted of $\frac{1}{50}$ of the gross load. On a road which is only in fair order, slightly cupped, or has an irregular surface, the tractive force exerted rises to $\frac{1}{33}$ of the gross load, while on a road having the surface covered with loose stones the draught or tractive force necessary to be put forth amounts to, at its worst, $\frac{1}{15}$ of the gross load.

3. The following are the general results of the experiments made by M. Morin upon the resistance of the traction of vehicles on common roads:—

1st. The resistance to traction is directly proportional to the load, and inversely proportional to the diameter of the wheel.

2nd. Upon a paved or a hard macadamized road the resistance is independent of the width of the tire, when this quantity exceeds from 3 to 4 inches.

3rd. At a walking pace, the resistance to traction is the same, under the same circumstances, for carriages with springs and for carriages without springs.

4th. Upon hard macadamized roads and upon paved roads, the resistance to traction increases with the velocity—the increments of traction being directly proportional to the increments of velocity above the velocity 3·28 feet per second, or about $2\frac{1}{4}$ miles per hour. The equal increments of traction thus due to equal increments of velocity are less as the road is smoother, and as the carriage is less rigid or better hung.

5th. Upon soft roads, of earth, or sand, or turf, or roads fresh and thickly gravelled, the resistance to traction is independent of the velocity.

6th. Upon a well-made and compact pavement of hewn stones, the resistance to traction at a walking pace is not more than three-fourths of the resistance upon the best macadamized roads, under similar circumstances. At a trotting pace, the resistances are equal.

7th. The destruction of the road is, in all cases, greater as the diameters of the wheels are less, and it is greater in carriages without than in those with springs.

4. Experiments were carried out by Sir J. Macneil on the road between London and Shrewsbury to ascertain the tractive forces required there, and measured by an instrument devised by him for the purpose. The general results, reduced to that on a level, as given by Telford,† are presented in Table II.

* Vide *Report of the Society of Arts on the application of Science and Art to Street Paving and Street Cleansing of the Metropolis*, 1875.

† *Seventh Report*, etc., p. 18.

TABLE II.

Description of Road.	Tractive Force per Ton.	Angle of Repose Represented.
Draught on a well-made pavement, ...	33 lbs.	$\frac{1}{68}$
,, broken stone surface on old flint road	65 ,,	$\frac{1}{35}$
,, gravel road, ...	147 ,,	$\frac{1}{15}$
,, broken stone road upon a rough pavement foundation, ...	46 ,,	$\frac{1}{49}$
,, broken stone surface on a bottoming of concrete, ...	46 ,,	$\frac{1}{49}$

5. It appears from experiments carried out at the Royal Agricultural Show at Bedford in 1874, by means of a horse dynamometer, made by Messrs. Easton & Anderson, that 1 lb. of draught was expended on moving every 35·1 lbs. of weight resting on a wagon with fore wheels of 41 inches in diameter, while on the hind wheels having a diameter of 60 inches it was 58·7 lbs. In the former case it was thus equal to a tractive force of 64 lbs. per ton with the smaller size of wheel, compared with 38 lbs. for that of the larger one, which latter figure practically agrees with those in the above table. Of the other trials at the same place with loaded wagons, having tires $2\frac{1}{2}$ to $4\frac{1}{2}$ inches wide, the average draught was $\frac{1}{49}$ of the gross load, or nearly 46 lbs. per ton. For single horse carts, loaded to about 30 cwt., the wheels of which were from 52 to 62 inches in diameter, and the tires $3\frac{1}{2}$ to 4 inches wide, the tractive force was found to be on a level macadamized road at a walking pace $\frac{1}{68}$ of the gross load, or $34\frac{1}{2}$ lbs. per ton. With other carts having wheels of slightly larger diameter and a greater load, the average draught under similar conditions was found to be $\frac{1}{51}$ of the gross load, or 44 lbs. per ton.

6. There can be no question that the smoother and harder the surface of a road is, the tractive force or draught necessary to move a vehicle will be less. It must also be apparent that the work of one horse on a level and well maintained road, may be easily increased two or three times, if the surface of the road is inferior in condition, by reason of any inequalities or ruts on the surface. In other words, four horses are enabled to do the work of five, or three of four, by keeping the roads in an efficient state of repair.

7. **Gradients.**—In ascending an incline the prime mover has to exert an additional force which has to be added to that of resistance on the level. This is approximately equal to the gross load divided by the rate of gradient. It can be shown diagrammatically what additional resistance is occasioned when the road is inclined against the load instead of being level.

In the accompanying diagram fig. 7, the whole weight is supposed to

be supported on one pair of wheels, being the simplest form in which this additional resistance may be investigated, and which can be shown in the following manner.

Let AB represent a part of an inclined road, D a vehicle sustained in its position by a force acting in the direction DG, DW the weight of the vehicle and load or the force of gravity acting vertically downwards. It is evident that the vehicle is sustained in equilibrium upon the inclined plane by these two forces, and, in addition, by the resistance of the road surface to the pressure of the vehicle acting at right angles to the incline of the road. To determine the relative magnitude of these three forces, draw the horizontal line BC and the vertical line AC; then since the two lines DE and AC are parallel and are both cut by the line AB, it follows that they must make the two angles DEF and BAC equal; likewise, the two angles DFE and ACB are equal; therefore, the remaining angles EDF and ABC are equal, and the two triangles DEF and BAC are similar. As the three sides of the former are proportional to the three forces by which the vehicle is sustained in equilibrium, so also are the three sides of the latter; viz., AB or the length of the road is proportional to W, or the weight of the vehicle and its load; AC or the vertical rise is the same to E, or the force required to sustain the vehicle on the inclined plane; and BC or the horizontal distance in which the rise occurs, to P, or the force with which the vehicle presses upon the surface of the road.

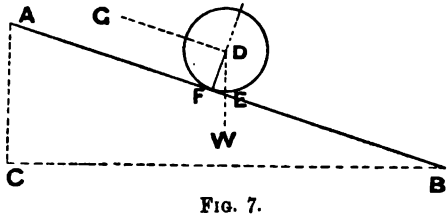


FIG. 7.

Therefore W : AB :: E : AC
and W : AB :: P : BC

And if BC be of such a length that the vertical rise AC of the road equals one foot, then the force DG will be represented by

$$\frac{W}{AB} = \frac{W}{\sqrt{BC^2+1}} = W \sin B$$

and

$$P = \frac{W.BC}{AB} = \frac{W.BC}{\sqrt{BC^2+1}} = W \cos B$$

in which B is the angle ABC.

These formulæ reduced to words are as follows:—

To find the force requisite to sustain a vehicle upon an inclined road, the effects of friction being neglected, divide the weight of the vehicle and its load by the inclined length of the road, the vertical rise of which is one foot, and the quotient is the force required.

To find the pressure of a vehicle against the surface of an inclined road, multiply the weight of the loaded vehicle by the horizontal length of the road, and divide the product by the inclined length of the same; the quotient is the pressure required.

The force with which a vehicle presses upon an inclined road is always less than its actual weight; the difference is so small, however, that on roads with a moderate inclination it may be taken as equal to the weight of the loaded vehicle.

To find the resistance to traction in passing up or down an incline, ascertain the resistance on a level road having the same surface as the incline, to which add if the vehicle ascends, or subtract if it descends, the force requisite to sustain it on the incline; the sum or difference, as the case may be, will express the resistance. The tractive power of horses varies according to their strength, speed, and the adaptability and training which they possess for any particular kind of work. An average horse will, travelling at a speed of $2\frac{1}{2}$ miles an hour, exert a pull of 110 to 120 lbs. on a level road with a smooth surface; while at a speed of 4 miles an hour, the draught exerted will only amount to from 65 to 75 lbs.

The tractive power of a horse becomes less as the speed increases, while in ascending inclines its power diminishes rapidly, a considerable portion of its strength, due to its own weight and that of the load, is expended in overcoming the resistance of gravity.

In ascending a perfectly smooth road, the amount of foothold afforded being less, tells more against the draught of a horse than one of ordinary roughness. The extreme comparisons may be taken as asphalte and macadam.

8. It is interesting to note that a horse is as strong as five men on a level, while on a gradient of 1 in 6 its tractive power is barely equal to that of three men.

Table III. shows the decrease in the loads in ascending gradients.

A horse can, however, exert for short distances twice to three times the average tractive power which he is capable of exerting continuously during a day's work, so that if the resistance on the gradient be not greater than double or three times the resistance on the level, the horse will be able to ascend such inclines with the gross load he is capable of drawing under ordinary conditions.

9. Professor Mahan deduced, from the results of experiments on tractional resistance carried out by Sir John Macneil, that the angle of repose is represented by the fractional part of the weight of the carriage, which, when applied to it, would be just sufficient to overcome the friction, and set the carriage in motion. In other words, the angle of repose for a well-made pavement would be represented, taking one ton or 2240 pounds as the load moved, as $\frac{33}{2240}$ or $\frac{1}{68}$ nearly, and the gradient for this class of road should not be greater than 1 in 68, or 1 perpendicular to 68 horizontal.

For the values of the angle of repose or the greatest inclination which should be given to a road made with different descriptions of material, see Table II. page 31.

TABLE III.

Effects of Gradients upon the Loads which a Horse can draw on a Macadamized Road, the Load on the Level being taken as represented by 1.

Inclination.	Angle.	Rise in feet per mile.	A horse can draw	Inclination.	Angle.	Rise in feet per mile.	A horse can draw	Inclination.	Angle.	Rise in feet per mile.	A horse can draw
	° ′				° ′				° ′		
1 in 10	5 43	528	·25	1 in 15	3 49	352	·325	1 in 20	2 52	264	·4
1 in 11	5 11	480	·265	1 in 16	3 35	330	·34	1 in 24	2 23	220	·5
1 in 12	4 46	440	·28	1 in 17	3 22	310	·355	1 in 25	2 18	211	·52
1 in 13	4 24	406	·295	1 in 18	3 11	293	·37	1 in 26	2 15	203	·54
1 in 14	4 5	337	·31	1 in 19	3 0	277	·385	1 in 30	1 55	176	·64

It is very desirable that in all cases the gradients should be reduced as much as practicable, as the extra exertion necessary to be expended by a horse in ascending steep gradients is considerable, and adds greatly to the cost of haulage.

Sir John Macneil, in 1836, maintained that no road was perfect unless its gradients were equal to, or less than, 1 in 40. M. Dumas, engineer-in-chief of the French Ponts et Chaussées, writing in 1843, recommended 1 in 50 as a maximum rate of inclination; whilst Professor Mahan considered, as a general rule, that gradients should be kept as low as 1 in 33. M. Dupuit recommends for the maximum gradient for metalled roads a 3 per cent. incline, or 1 in 33, and for pavements a 2 per cent. gradient, or 1 in 50. The gradient of 1 in 30 adopted by Telford is such that, in ascending it, a horse can easily put forth the force necessary over and above the pull needed for taking the load along the level. Gradients of 1 in 20, and even steeper, have at times to be introduced at points in the line of a proposed road, to obviate heavy expenditure in the construction of the works. On the other hand, a road should not be constructed on a 'dead-level,' but have a minimum gradient. This, although applying in a certain degree to traction, has reference more particularly to the maintenance of roads, and will, therefore, be treated in its proper place.

10. Wheels and Weights on them.—The imperfect condition of the roads at the beginning of the present century was such that regulations were embraced in the Acts relating to highways, enforcing that wheels of vehicles should be of great width in proportion to the weights carried. Table IV. gives these particulars.

TABLE IV.

Weight, Horse-power, and Wheels of Vehicles on Common Roads, 1809.

Breadth of Wheel.	Gross Weight.	Number of Horses.	Draught of each Horse.	Weight on the road at each Wheel.	Pressure per inch of Width.	
Inches.	Tons.		Cwt. lbs.	Cwt.	Lbs.	Cwt.
16, . . .	8	10	16 0	40	280	2·50
9, rolling 16,* .	6½	8	16 42	32½	404	3·60
9, . . .	6	8	15 0	30	373	3·33
6, rolling 11, .	5½	6	18 37	27½	513	4·58
6, . . .	4½	6	16 0	22½	420	3·75
3, . . .	3½	4	17 56	17½	653	5·85
2, Stage Coach, .	4	4	20 0	20	1120	10·00

From the foregoing table, it is apparent that the pressure per inch of width of tires at the surface of the road increases as the width diminishes. It was the opinion of practical men using the roads during that period, that a pressure of 4 cwt., or 448 lbs., per inch of width should not be exceeded; while the tire of the wheel should be limited to a minimum width of 4½ inches. Unquestionably a tire of moderate width, provided the weight distributed over it is not excessive, may be looked upon as one to be recommended.

11. Conical Wheels.—The excessively wide rounded tires and conical shape of the wheel in use in the early part of the century would appear to be the worst combination that could possibly exist. It is apparent that a conical wheel can only be made to travel in a straight line by a constant twisting action at the surface of the road. Consequently, the wider the tire, the greater is the twisting and disintegrating action by the wheels on the material composing the crust of a road. The cylindrical wheel, with flat tires of moderate breadth, is the best possible form for easy traction, and by its use less wear is occasioned to the road-surface.

The practical advantage in the dished or slightly conical form of wheel is that a wider space is afforded for the body of the vehicle, and the inclined spokes forming this class of wheel tend to resist the lateral shocks to which they are subjected at times. Although the cylindrical wheel was strongly advocated, and encouraged by many turnpike trusts, in the form of a reduction of tolls, still the dished or conical form of wheel has become almost of general use. Provided this class of wheel has a flat or but slightly rounded tire, 4½ inches in breadth, little can be said against its use.

* The rolling widths are the slant widths of conical wheels.

12. The General Turnpike Act (1823) regulated the weights to be carried by wagons, carts, etc., with wheels having tires varying from 4½ to 9 inches in breadth, the weights allowed being generally 10 cwt. less in winter than those carried during the summer months. Wheels having tires of a less width than 4½ inches were not so restricted. Consequently, it was possible to carry with tires 2½ inches in breadth the same weight as was allowed for wheels having tires 4½ inches in width. The extra toll imposed on carts with narrow tires did not, however, prevent their use, and after the tolls were abolished they became general, and are now to be found on far the greater proportion of vehicles travelling on the highways.

Sir J. Macneil, in his evidence before the Committee on Steam Carriages in 1831, gave the following particulars as to weights of coaches and wagons, and the pressure per inch of width of tire.*

TABLE V.

Description of Vehicle.	Weight on the Average.	Breadth of Wheel.	Pressure of each Wheel.	Pressure on each inch of Breadth.
Mail Coach, . . .	2 tons	2¼ inches	10·0 cwt.	4·40 cwt.
Stage Coach, . . .	2⅛ ,,	2 ,,	12·5 ,,	6·25 ,,
Van, ...	4½ ,,	2½ ,,	21·25 ,,	8·29 ,,
Wagon, ...	6 ,,	9 ,,	30·0 ,,	3·33 ,,
,, ...	4½ ,,	6 ,,	22·5 ,,	3·75 ,,
,, ...	3½ ,,	4 ,,	17·5 ,,	4·37 ,,

It will be observed that the weight per inch of tire is exceedingly high for vans as compared with wagons, the tires of which were 9 inches in width. As the edges of narrow tires become rounded through wear, it is evident that the pressure per inch of width will in time become greater than that tabulated, even to the extent of 25 per cent.

13. The Acts relating to the weights allowed for wheels with tires of different width having been repealed, County Authorities were empowered to make by-laws, under the Highways and Locomotives Act of 1878, for regulating the width of wheels in relation to the weight carried. In those counties where such powers have been exercised, the practice usually followed was to adopt the weights allowed under the General Turnpike Act, with any modification which was considered necessary for the varying conditions in different parts of the country.

14. The weights on wheels under the different conditions to which roads are now subjected vary considerably, according to circumstances, as may be gathered from the following, bearing more particularly on the effect produced by vehicles having wheels with wide tires.

* *Evidence, Committee on Steam Carriages*, p. 95.

It is a difficult matter to conceive how it is possible that a rigid wheel with a tire having a breadth of 18 inches can bear equally on the surface of a road for that width. From the manner in which these wheels are constructed they present a rigid flat surface, and this has to travel on a road having a transverse surface convex in form. The amount of convexity varies according to circumstances, and in the form least necessary for surface drainage it presents the part of a circle, or by two inclined straight lines from either side joined by a curve in the centre. Under these circumstances the point of contact of the wheel on the road-surface will be confined, theoretically, to a single point which is the inner edge of the tire. The rise generally given to a road-surface transversely is such that with tires of moderate width the pressure is uniform over the full width, but in the case of vehicles having tires of great width a portion only of the breadth transmits the whole weight to the surface of the road.

Macadam gave it as his opinion, in his evidence before the Select Committee on Steam Carriages, 1831, that no advantage was gained by increasing the breadth of the tire above 4½ inches, as a greater breadth could not at one time touch the surface of a well-formed road. Similar results were obtained by Morin from actual experiments carried out with vehicles having wheels with cylindrical tires of 2·5 inches, 4·6 inches, and 7 inches in width, respectively. These results, concisely stated, showed that over 30 per cent. more tonnage can be carried over a road in good order, on wheels having tires 4½ inches wide, than can be done on wheels with tires 2½ inches wide; the wear or damage resulting to the surface of the road being about the same in each case. It was also observed that any excess of width of tires beyond that stated had no compensating value.

15. It would appear from these conclusions that wheels of wagons and other vehicles having tires of from 6 to 9 inches in breadth, traction-engines with rigid tires having a width of from 15 to 18 inches, and the driving or hind wheels of steam road-rollers with rims 18 to 20 inches wide, are powerful agents in destroying the crust of a road. In the case, however, of wagon wheels with tires beyond 4½ inches in breadth, as also the driving-wheels of steam road-rollers, this want of equal bearing surface, owing to their rigid construction, is found not to apply after they have been in use for some time. The inside edges of these wheels for a time carry practically all the weight, but in time they conform through wear, especially in the case of rollers, to the transverse convexity of the road surface.

16. **Traction-Engine Wheel Tires.** — In traction- or road-engines having the ordinary rigid tires, with diagonal bars at the periphery, this wearing away or conforming to the section of the road does not take place, or at least to a very limited extent. In the nature of the work of these engines travelling over all conditions of roads in an indifferent state of repair, the flat form of the tire practically remains unaltered, except, pro-

bably, the edges get somewhat rounded. This rounding still reduces the bearing-surface, in some cases by 3½ inches, even should it bear equally in the case of a road, of which the surface is considerably worn, and consequently flat transversely.

TABLE VI.

Showing Weights carried by various Vehicles under varying conditions.

Description of Vehicles.	Width of Tire.	Load on Wheel.	Load per inch of Width of Tire.
	Inches.	Cwt.	Cwt.
Traction-Engine weighing 12 tons in steam, two-thirds of weight on driving-wheels, and bearing equally throughout their width,	18	80	4·44
Traction-Engine, with a bearing-surface of 50 per cent. of actual width of wheel,	18 – 9	80	8·88
Traction-Engine, with a bearing-surface of 25 per cent. of actual width of wheel,	18 – 4½	80	17·76
Traction-Engine weighing 9 tons in steam, two-thirds of weight on driving-wheels, and bearing equally throughout their width,	16	60	3·75
Traction-Engine, with a bearing-surface of 50 per cent. of actual width of wheel,	16 – 8	60	7·50
Traction-Engine, with a bearing-surface of 25 per cent. of actual width of wheel,	16 – 4	60	15·00
Steam Road-Roller, with scarifier attached, weighing 16½ tons in steam, three-fifths of weight on driving-wheels,	18	97·50	5·42
Steam Road-Roller, do. do.	20	97·50	4·88
Wagon for Steam Traction, weight 30 cwt., load 6 tons, bearing equally on tire throughout the full width,	8	37·5	4·69
Wagon for Steam Traction, with bearing-surface of 56 per cent. of actual width of wheel,	8 – 4½	37·5	8·33
Wagon for Steam Traction, weight 28 cwt., load 4 tons, bearing equally on tires throughout the full width,	6	27	4·50
Wagon for Steam Traction, with bearing surface of 78 per cent. of actual width,	6 – 4½	27	6·00
Wagon for Steam Traction, weight 25 cwt., load 3 tons,	4	21·25	5·31
Horse Wagon, weight 21 cwt., load 2 tons,	2	15·25	7·62
Cart, weight 9 cwt., load 35 cwt.,	4	22	5·5
Cart, weight 9 cwt., load 31 cwt.,	2½	20	8·0

From the above it follows that the bearing-surface at the point of contact between the wheel and the road is reduced to one-half, and sometimes even less, on a road having the surface properly formed transversely. On a road well worn or comparatively flat, the pressure will be distributed over a

greater surface, and in the event of such surface being worn so that it forms a level transversely, then, and then only, can the full width of the wheel bear equally on the road. It need hardly be pointed out that the surface of a road under such conditions is in a state of disrepair, when it cannot be expected to bear even the distributed weight which such conditions make possible.

Table VI. illustrates very forcibly the conclusions arrived at in the preceding paragraphs.

The effect, on the surface of a road, of the passage of a traction-engine, during and immediately after a fall of rain, when the surface is slightly covered with mud, clearly proves the foregoing statements. On a flat transverse surface the full width of the wheel tire is clearly defined; on a road having only a moderate curvature, the extent of the impression caused by the passage of the engine wheels may vary from 75 per cent. to 50 per cent. of their actual width of tire; while on a road with a transverse curvature or convexity according to present practice, an impression of not much more than 25 per cent. of the actual width of the wheel tire is visible on the surface of the road.

It is evident, therefore, that in the case of a traction-engine, the wheels of which only touch the road surface for $4\frac{1}{2}$ inches of their width, a very heavy strain is imposed on the material comprising the road covering. During dry weather this excessive weight causes a considerable amount of abrasion of the material at the surface of the road. When thaw succeeds frost, and the immediate surface of the road coating is in a somewhat loose state, the passage of traction-engines has the effect of greatly disturbing the materials of the road-crust on roads generally, and is extremely trying even on those which are repaired with the best possible class of macadam and maintained in the best condition. It often happens, after alternating frost and thaw, that the road coating is affected to a greater or less depth; and at such times the passage of a traction-engine over a road causes considerable damage by crushing the stones comprising the coating, and in many instances lifting and displacing patches of the material.

17. Vehicles with Narrow Wheels.—Vehicles with narrow wheels carrying heavy loads cause much damage under similar conditions, particularly on a road where, with but little passing traffic to cause the vehicles to follow a zigzag course and change their position, they run in tracks and form hollows in the surface. The increased cost of maintaining roads under these circumstances clearly points to the necessity of having improved tires for vehicles, or of adopting more stringent measures for regulating such traffic under the adverse conditions alluded to.

18. Improvement of Traction-Engine Wheel Tires.—More particularly in the case of traction-engines does the necessity exist for some form of flexible driving-wheels which would, by the construction of the tires, dis-

tribute the weight in a uniform manner over the actual width of wheel, and at the same time minimize vibration, which in the ordinary traction-engine causes considerable damage to buildings situated near the road traversed.

Attempts have been made from time to time to attain this object, and while in many cases the vibration has been considerably reduced, the rigid tire has always been conspicuous by its presence.

Boulton's flexible wheel, patented some years ago, has supplied in a great measure the requirements so necessary for the effective distribution of the weight to the surface of the road, and the elimination of vibration.

The description of this wheel, or rather the tire, may be briefly stated as follows:—The driving-wheel is 7 feet in diameter and 16 inches wide. The periphery of the wheel consists of a deep rim divided into sixty-eight cells or compartments, two in the width of tire and breaking joint with each other. Into these cells, which are about 6½ inches square and 9 inches deep, hard-wood blocks are fitted, with an allowance for a suitable amount of radial play. Each block, with the grain of the wood pointing outwards, is bound round, near the lower end, with an iron band. The blocks rest on an india-rubber cushion 5½ inches square and 1 inch thick, or some other elastic material sufficiently yielding to absorb the jar while working. The blocks are attached to the inner rim of the tire by a bolt let into the wood block several inches; it then passes through the elastic pad and inner rim, and is secured by a nut. The recess at outer end of block is fitted with a wood plug. As the wheel revolves, the weight comes on three, four, or five blocks, the indiarubber pads are compressed while the bolts work freely in the slot of the inner rim, and the blocks adapt themselves to the surface of the road.

With this class of tire it is evident that, as four or more of these hard-wood blocks bear on the road surface at the same time, the weight is distributed both transversely and longitudinally. By this arrangement the pressure on the road is considerably reduced, the weight being spread over a considerable area. In the case of a traction-engine weighing 12 tons, the pressure with three blocks in contact with the road surface only amounts to a little over ½ cwt. per square inch.

It will be readily understood that, apart from doing any damage to the road surface, the engine is much more efficient, especially when ascending steep gradients, by reason of the increased contact surface afforded by the wood blocks. As showing that traction-engines fitted with Boulton's patent springs cause little or no damage to the roads, it may be mentioned that the Ashton-under-Lyne Town Council do not charge a travelling fee for them when they pass through that borough. When moving the confirmation of the minutes recording this arrangement, the Mayor said:—"The Council would see from one of the minutes that the committee had agreed to accept, without cost, traction-engines fitted with Boulton's patent spring wheels.

They found that these wheels did little or no damage whatever, and they thought it would pay them better to admit these engines than admit other traction-engines with the ordinary wheels at the usual payment."

19. Excessive Weights on Wheels.—Heavy weights carried on vehicles with narrower tires than 4½ inches cause considerable wear even on a hard dry road, and, as has been pointed out, the damaging effect during alternating frost and thaw is a very serious matter. The proper width of tire, or proper load upon any vehicle for a given width of tire, is a question which deserves more attention than is usually accorded to it.

The by-laws controlling the weights to be carried on wheels should certainly restrict these weights to about 5 cwt. per inch of actual bearing surface on vehicles without springs. This pressure is almost similar to that exerted by a 15-ton road roller which makes the road for the traffic. If the weight carried on the tires of any description of vehicle were not to exceed this standard, infinitely less damage would result to the road surface, and a corresponding decrease in the cost of maintenance would be effected. Vehicles in a state of disrepair, such as those having a slightly bent axle or an excessive play between the nave and axle, aggravate the evil, and also create an additional burden on the horses drawing the vehicles.

Sir J. Macneil stated before the Committee on Steam Carriages in 1831, that, from his experience on the road between London and Shrewsbury, he considered a wheel should have a tire an inch in width for every 5 cwt. of load. Telford was of opinion that the weight should not exceed 1 ton upon each wheel; while Macadam, speaking from his experience of the Metropolitan roads, considered that the maximum load should not exceed 9 cwt. per inch of width of tire. This latter weight is undoubtedly too much for roads even in first-class repair.

20. Effect of Springs on Vehicles.—Experiments have shown that vehicles on springs diminish the wear of roads, especially at speeds beyond a walking pace. Going at a trot, they were found not to cause more wear than vehicles without springs at a walk, all other conditions being similar. Vehicles with springs improperly fixed cause considerable concussion, which in its turn destroys the road coating. If the surface of the road be irregular, there is increased draught, and this also means additional wear by the horses' feet.

The size of a wheel has also an important bearing on the wearing of roads, a wheel of small diameter causing relatively much more wear than one of large diameter. Wheels of the common size, or about 6 feet in diameter, are considered best; they also reduce the draught for the horses.

CHAPTER II.

LAYING OUT NEW ROADS, AND THE IMPROVEMENT OF EXISTING LINES OF COMMUNICATION.

THE selection or location of country roads is carried out by making an examination or reconnaissance of the tract of country to be traversed, so as to obtain the requisite data for the purpose of determining the best route and gradients for the proposed line of communication.

21. The most direct or shortest practicable route between two points at once suggests itself; but this, in every case, must be governed by the natural features of the surface of the country. The object aimed at is to ascertain the most favourable direction in which to lay out a road, so as to convey the traffic with the least expenditure of motive power consistent with reasonable economy in construction and in the subsequent maintenance of the road and works.

22. "Economy of motive power is promoted by low summit-levels, flat *gradients* (as the rates of declivity of lines of land-carriage are called), easy curves, and a direct line; but limitations to the height of summits, the steepness of gradients, and the sharpness of curves, limit also the power of adapting the line to the inequalities of the ground, and so economizing works." *

In a thickly populated district the new line of communication is to a certain extent predetermined by the existence of towns and villages, while in a sparsely populated tract of country greater liberty in selecting the route to be followed is permissible, as the natural character of the country alone would form the basis for selection.

In either case the engineer, in laying out the line of a new road, must be governed by the principles laid down in the preceding chapter, in so far as the gradients are concerned.

23. Reconnaissance.—The general series of operations preliminary to the formation of a new line of communication are the examination or

* Rankine's *Civil Engineering.*

reconnaissance of the country between the points to be connected, taking note of the physical features of the country, its geological formation and sources from which materials for construction may be obtained, and the probable requirements of the district to be passed through. In this work the engineer will be greatly aided by obtaining the best and most reliable maps of the district. Flying-levels are generally taken concurrently, in order to ascertain the elevations of detached points, such as passes across ridges, and valleys, also points where structures of magnitude may be required.

24. General Principles to be observed in the Field.—In laying out a line for a new road, the following data should be carefully noted and recorded in the field-book:—

Examine the inclination of the strata, their nature and condition as to dryness.

Have the surface of road exposed as much as possible to the action of the air and sun's rays.

Cross valleys and passes at right angles.

Examine beds of rivers at proposed crossings and up and down stream, with a view to secure stable foundations for bridges, culverts, etc.

Examine sources, accesses, and distances of the supply of material for the erection of structural works, and for stones suitable for the road-covering.

Ascertain accurately the level of all existing lines of communication, such as railways, roads, canals, and of rivers and streams.

25. Method of selecting Final Route.—It is advisable, before finally fixing the direction which a new road may take, to lay out two or more trial lines in order that a comparison can be made and it may be seen which so far complies with the following requirements. One of the principal conditions which every line of communication should satisfy is that it connects the two points by the shortest practicable route consistent with flat gradients and economy of construction. A uniform gradient can always be obtained, when there is a continual rise of the ground from the point of departure and the point where the road crosses the ridge, in a serpentine course, by following the sinuous and irregular formation of the ground. It is necessary to join the straight portions of the line at the points of change of direction by curves, concave towards the hollows, and convex going round the projecting spurs of land. A return to the straight line is advisable, and should be given effect to at every opportunity. It is also essential that a uniform ascent be obtained between the two points which are to be connected, in order to avoid unnecessary ascents and descents, thus causing a loss of motive power. Long reaches of level, especially in cuttings, should be avoided, as they add to the difficulty of drainage, and to the subsequent cost of the maintenance of the road.

26. Roads in Mountainous Districts.—In very hilly districts the route may have to be formed in a zigzag fashion in order to maintain the 'maximum' gradient. It is advisable that the curved portions (which are generally somewhat abrupt), connecting the straight sections, should have the gradient reduced so as to conduce to the safety of vehicles descending. The gradients of roads may be classed into those suitable (1) for fast traffic; (2) for mixed traffic; and (3) for ordinary agricultural transit. The first will be best satisfied with maximum gradients of 1 in 50, the second with gradients of 1 in 30, and the third with gradients of 1 in 20. These gradients should, if possible, be strictly adhered to; but under certain conditions, the physical features of a district involving great expenditure in the construction of the works, gradients for short distances may be increased to 1 in 30 for fast traffic, and 1 in 15 for agricultural haulage. Marshy or very wet soils should be avoided, owing to the difficulty of obtaining a firm foundation for the road, and such places can only be made satisfactory by an effective system of drainage, the cost of which would, in most cases, greatly exceed the additional expenditure incurred by deviating from the proposed line, even though this should entail a considerable detour.

27. Topography.—As bearing upon the general information necessary to successfully lay out a line of communication, it is advisable, when exploring a district, to observe the following positions, which are of primary importance.

The physical features of a tract of country present an undulating and irregular formation, and endless varieties of forms and combinations. On close examination, however, two classes of lines or conditions of formation are perceived to exist, which go to make up the general form of the surface of the earth. These are called ridge-lines and valley-lines.

28. Ridge-Lines.—A ridge-line is distinguished by the property that along the whole of its course it is higher than the ground immediately adjacent to it on either side; it is seldom straight or level throughout any considerable part of its length, and is generally irregular both vertically and horizontally.

The lower points or depressions on a ridge-line are termed passes; the best point to cross a ridge is generally by one of the lowest passes.

29. Valley-Lines.—A valley-line, on the other hand, is distinguished by the property that along the whole of its course it is lower than the ground immediately adjacent to it on either side; or, in other words, the ground slopes upwards from it on both sides. Being the lowest point in the adjacent surroundings, the water on the surface of the ground necessarily flows towards the valley-line and, except when it is landlocked, runs along it in streams, sometimes called 'water-course lines.' Like a ridge-line, a valley-line is seldom level or straight throughout any considerable part of its length.

Rivers intersect the country in various directions, and between their point of discharge at the sea and the interior, the main or larger river is joined in its course by lesser ones or tributaries, which, in their turn, are joined by brooks and rills.

30. Maps.—Old maps or plans of a country showing the rivers and principal water-courses give a tolerably good idea of the direction of the valley-lines, while the Ordnance Maps of Britain, on the scale of six inches to one mile, show the principal contour-lines at every 50 feet of elevation in the flatter parts of the country, and at every 100 feet of elevation in the more hilly parts.

The latter are of great value to the engineer, as a means of enabling him to select the best line for the trial sections of a proposed line of road.

A projected road may be limited to the connecting of several points in the same valley, or it may have to connect points in two or more valleys. In the former case, the line of communication may be wholly situated on one side of the river or stream, which is the simplest case met with in practice. On the other hand, the points to be connected may be situated on the opposite sides of a valley and separated by a river; while in extreme cases, such as in a narrow valley, owing to the physical features of the ground, the line of the proposed road may have to be carried over the river or stream several times where the waterway cannot be deviated, or when a suitable line for the road cannot be obtained except by a deep rock-cutting or tunnel. In carrying out an extensive road system, it often happens that all the cases mentioned have to be dealt with, frequently perhaps, throughout its course.

31. When practicable, the line of road should be laid out on the driest ground available, and its position should be such that the surface is exposed to the joint action of sun and wind. Roads made in the lowest parts of a valley are subject to flooding, while those running along the side of a hill, especially where the strata dips towards the valley, are liable during and immediately after a storm of rain to suffer from land and earthwork slips, as well as surface-washings.

32. Longitudinal and Cross Sections.—In taking trial sections the method usually followed is to supplement the information by taking, at different points (especially where the surface of the ground is irregular) along the line or route, cross-sections of considerable length. This gives a good idea of the best direction which the centre-line of the intended road should follow in order to avoid, as much as possible, unnecessary cuttings and embankments.

In explanation of this, let A B, fig. 8, be a portion of the proposed road, and *c c* the breadth of country under consideration for this purpose. At any points along the line, depending on the changes of level of the surface of the ground, *s s*, contour-lines are measured off and fixed at right angles to

A B. These lines should be accurately levelled, and then drawn on the plan of the line of road.

The etched lines show the form of the surface of the ground along the lines A B and *c c* on the plan, and there is no difficulty in seeing the extent of cutting and filling required, and in determining how the position of the intended line may be varied with reference to the natural surface of the ground, so that the cost of construction may be reduced to the smallest possible amount. When two or three trial sections are taken between the same points, the various lines should be compared in order to ascertain their relative advantages. If the centre-line be changed in position after due consideration of the foregoing, care should be exercised in laying down regular curves of proper radii to join the straight portions in the altered position of the line of road.

33. Laying Out Grade-Line in Hilly Districts.—Another method is sometimes followed when working in a gradient round the face of a hill in mountainous districts where the maximum gradient must be kept sight of continually. The lower portions of the hills in approaching valleys are

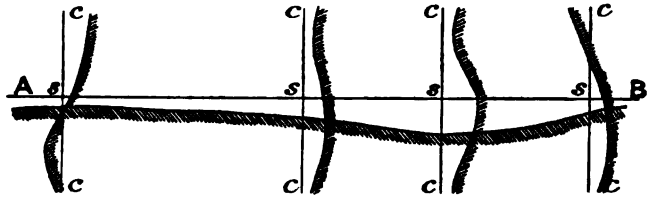


FIG. 8.—Trial sections.

generally flatter than those at and near the summit, and the line of road may be carried out in any desired direction which will be a continuation of the portion of road from the higher points. The proper course is to start the trial section from the pass at the summit and work downhill, the maximum gradient line being staked off, and the position afterwards surveyed and laid down on the plan, when any irregularities in the line may be corrected so as to show regular curves.

Resting-places, or comparatively level stretches, are sometimes introduced when the gradients are steep and continuous: these should be provided at convenient intervals along the line of road.

34. Loss of Height.—In selecting the position for a proposed road, care should be exercised, as already pointed out, to avoid useless ascents as much as possible when a subsequent descent must be made, and the reverse, that is, introducing an intermediate rise in a descending gradient. An instance of this, owing to the manner in which the road was laid out with numerous and extensive useless ascents, has been noticed in the historical sketch, page 26.

35. Working Plans and Sections, Staking Out Centre-Line, Specifications and Estimates.—Subsequent to these preliminary operations, the survey for the working-plan is commenced, on which is delineated the centre-line of the intended road as finally fixed upon. The centre-line is then transferred on to the ground and pegs driven in at intervals, the end of the straight portions being indicated by two pegs. This operation is carried on until the whole length of road has been staked off, when the working-section is proceeded with.

This longitudinal section of the route is based on accurate levellings and measurements taken along the centre-line as staked out, and afterwards laid down on paper to suitable scales, with a horizontal line showing the datum, a line representing the surface of the ground, and lines marking the levels of the proposed work. The apex, or meeting-point of all gradients, should be rounded off by a vertical curve, as shown in fig. 9. Information as to depth of cuttings and height of embankments and other relative matter should be marked in figures on the section. Level-pegs, numbered from 0 upwards, are driven into the ground at regular distances of 100 to 300 feet, depending on the irregularity of the surface of the ground, cross-sections

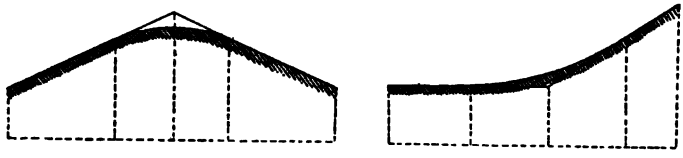


FIG. 9.

being taken at these and other intermediate points if necessary, and plotted on the longitudinal section to a natural scale. Bench-marks of a permanent nature should also be established at certain fixed points, such as near the site of a bridge or at a change of gradient. When this is accomplished, the detailed drawings of the various works embraced on the line of road can be completed, and the quantities of earthwork in the cuttings and embankments ascertained, when an estimate of the probable cost of constructing the road can be made with a certain degree of accuracy. To ensure greater precision, trial pits and borings are sometimes made with a view to ascertain the nature of the strata of which the ground is composed along the line of works, which information, apart from its immediate use in forming a correct estimate of the cost, should be marked on the plan and section for future reference.

36. Intermediate Towns.—It will be a matter for consideration, in laying out a proposed new road between two distant points, whether or not the towns which are situated at some distance from the line of communication projected should be accommodated by branch roads striking off the direct road, so that all the towns and villages within reasonable dis-

tance may be put in mutual connection. Commercial considerations, as well as the physical character of the ground, must govern this to a great extent. Assume in the following instance that A and B, fig. 10, are two important towns which it is desired to connect with as direct a road, and with as easy gradients, as the nature of the intervening ground will admit of, and that at some distance from A there is, on one side of the direct line, an intermediate town C, where an industry, though limited, is carried on. Examination, however, shows that the village C is situated at a considerably higher elevation than the proposed road between A and the point D, and onwards for some distance in the direction of B. This physical condition or difficulty would, if C were put in direct connection with A and B, and indicated by the dotted lines A, C, E, practically convert what would otherwise be a well-laid-out road, having easy gradients, into one having steep inclines, necessitating a useless expenditure of motive power in transporting merchandise along what would then be the main road if C were on the direct line. It is manifest, therefore, that the town represented by C would be better accommodated, having regard to the traffic on the line of communication A B, by making a branch road C D.

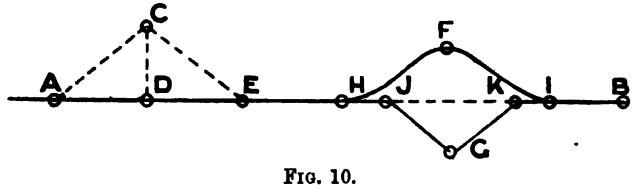
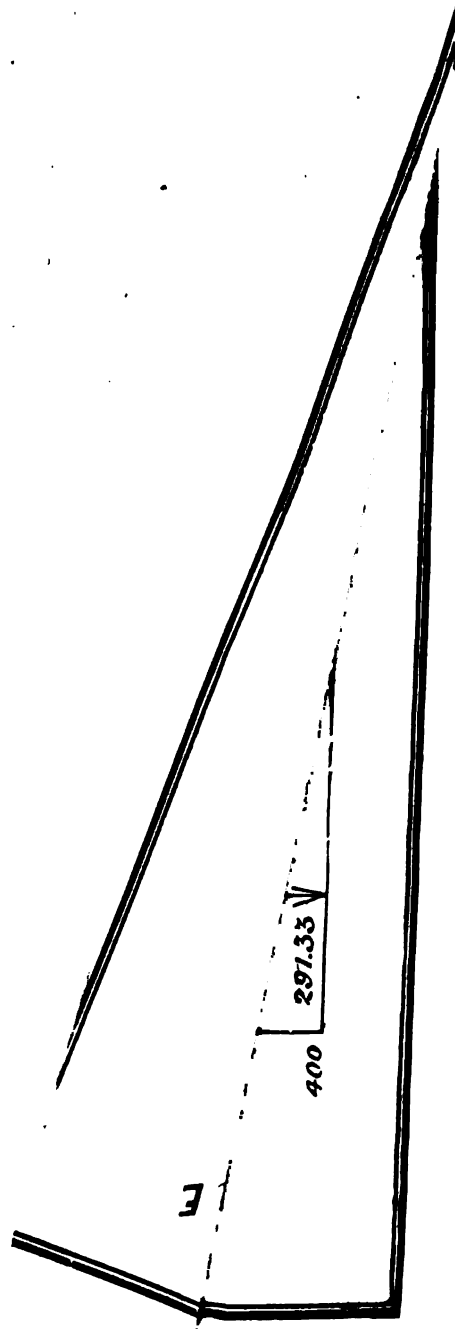


FIG. 10.

Further, in the direct line towards B there are two rising villages, F and G, from which a considerable prospective traffic is expected between the principal towns A and B, and *vice versa*. It is desirable that each should be situated so that the main road will pass through them, but it is apparent that this arrangement is impossible, as the detour, apart from any other consideration, would be very great, adding materially to the length of the main road.

Branch roads could be laid down at right angles to the main road, but the extra haulage, and consequent enhanced cost in the selling-price of goods, demands some consideration. Assume that the traffic from each of the points F and G will amount to about the same tonnage, therefore an equal claim, so far as traffic is concerned, exists in either case for direct communication. The physical character of the ground at and from these points in relation to the line A B will, however, decide which village should have the advantage of being placed on the main road. If it is found on examination, and after running trial-sections from the line A B to F and G, with a view to deviate the direct road, that the ground towards F is



[To face p. 49.

practically the same as on the direct line, while at the point G it is somewhat lower, and the surface of the ground in the direction of J and K very irregular, it is quite clear through which village the main road should pass.

The route thus decided upon will therefore follow the letters A, D, E, H, F, and I to B. The point G may be connected by a line from there towards the main road A B at J or K, but as this would entail considerable extra haulage in a direction opposite to that in which the connecting road may be fixed upon, it is evident that this arrangement would affect the traffic from G to a considerable extent, and other means calculated to avoid this detour are obviously necessary.

This can be effected by laying down two branch roads G J and G K, and the point G may now be considered in as good a position in relation to the main road as the point F. It must be remembered, however, that the gradients, as has already been pointed out, from G to J and G to K are not so favourable to traction compared with the deviated part of the direct line H, F, I. The saving in transport on the shorter route will be proportionate to the tonnage carried, and assuming the distance saved to be one mile, it is evident that a saving of sixpence per ton at least would be effected on each ton of goods conveyed between these two points, which would represent a considerable sum of money per annum.

37. Laying out New Roads in actual practice. — In the following instance, taken from actual practice, the object in view was to lay out a new line of communication to connect two existing roads running nearly parallel, and at a distance of about 1½ miles from each other.

The existing roads are situated in separate valleys, with a hill or ridge intervening, and the only connection between them was formerly by a road having gradients at several points of 1 in 18, and at one or two points 1 in 10. By the construction of the new road a detour or saving in distance of 1¾ miles was effected.

The class of traffic to be accommodated consisted of fast and slow vehicles, in other words, mixed traffic, and a maximum gradient of 1 in 30 was therefore fixed upon as that fulfilling, under the circumstances, the conditions already laid down in this and the preceding chapter. Fig. 11, Plate I., shows the two existing and nearly parallel roads, A, B, C and D, E, F, while the cross road, which formed the only connection between these previous to making the new one, is shown at A D on plan. Owing to a continued and increasing traffic to and from the coast in a south-westerly direction, it was considered desirable to establish a more direct route, having gradients over which fast traffic could be conducted without much inconvenience to the prime mover. The first matter necessary to be determined was at what point the intended road should leave the existing one between A and C. Fig. 12 shows a longitudinal section of this road, and as the new road must necessarily start on a rising gradient, it is evident that

the most suitable spot of departure is at B, because it is the highest point on the existing road. This point, therefore, was fixed on as the starting-place for the intended road. The point of arrival on the road D F had likewise to be determined, and on referring to a section of this road, fig. 12, it would appear the further east, or in the direction of D, the junction was made, that the gradients would be flatter. No doubt this is the case, but, on the other hand, this would to a certain extent defeat the object in constructing the new road, namely, that of as direct a route as possible. By going too far in the direction of F an unnecessary ascent would have to be overcome which would only make the new road longer without any compensating advantage.

The point E was therefore fixed upon as the termination of the intended road and junction with the existing one, D F.

The first consideration in laying out a new road being that of a direct route, a trial line may be drawn on plan, fig. 11, between the point of departure B and the terminal point E, in order to show, in this particular instance, that the shortest route must be subservient to that having suitable gradients. A section of the intervening ridge between the existing roads situated in the two different valleys, made from the contour lines on plan, clearly shows that such a route is impracticable, owing to the steep ascents and descents on either side of the ridge. This can generally be seen at a glance, as the steepest parts of the surface of the ground are at right angles to the contour lines. The route for the new road had therefore to be laid out along the slope of the hill in a direction tending towards E; and crossing the ridge at its lowest point or pass G, the line of road was then continued in a southerly direction to its termination at E.

On referring to the Ordnance Map, a reduced copy of which is shown in fig. 11, it will be observed that the summit level is 384·00 feet, while the height of the existing road at the point B is 134·00, or a difference of 250·00 feet. The approximate length of road between these points was ascertained to be about 8180 feet, giving a uniform gradient from B to G somewhat easier than 1 in 30. As this was the rate of inclination originally fixed upon, and as there would be no necessity under the circumstances to form a heavy embankment immediately south of the point B, where the ground is low, which would be the case if the maximum gradient were commenced from the existing road at that point, it was decided to lay out the portion from the point B for a distance of 289 yards with a gradient of 1 in 50.

The difference of level in comparison to the length of road also admitted, having regard to the maximum gradient fixed upon, of a short level stretch being introduced on the line of new road midway between the point B and the summit G.

The method followed in laying down the approximate route was to start from the fixed point G, and stake out the maximum gradient line, on

the surface of the ground, down hill on the north side of the ridge. A somewhat similar process was carried out in fixing the direction of the line between the summit and the point E, being the lowest point of the valley at the stream, and requiring an embankment of considerable height.

The whole length of the proposed route was then surveyed, and the horizontal position of the gradient pegs carefully plotted on the plan as shown, with dotted lines between them. The method here pursued, owing to the irregular formation of the ground, necessitated the route following a sinuous course.

The final line was then adjusted on the plan, following the position of the gradient pegs as near as possible, in giving the line a regular course with straight lines and easy curves, regard being paid, with a view to a moderate outlay of capital, to equalize as much as possible the cuttings and embankments. The alignment of this road, although following to a considerable extent a sinuous course, does not add in any appreciable degree to its length compared with a practically straight road along and down the side of the hill. A sinuous course is in most cases a decided advantage, from a maintenance point of view, as on a winding road the wheel traffic spreads over the whole surface, which seldom takes place on a straight road, especially when level horizontally.

The route was then staked out on the ground, and the final detailed or working section prepared, with numerous cross-sections taken at convenient points, to determine exactly where retaining walls were necessary to supplement the earthworks in forming the road. The longitudinal section in such cases should also have marked on it the level of the ground, the level of the proposed work, and the height of embankment or depth of cutting, at numerous points, where the level of the ground has been taken; these should be found by calculation and not by measurement from the plans.

The trial-section of this road showing the gradients is illustrated at fig. 12, Plate I., and the working-section of a portion of the road is shown at fig. 12A, Plate I. Detailed drawings of bridges, culverts, retaining walls, and the road covering should be provided, and a detailed written specification prepared showing the manner in which the embankments, excavations, masonry, and other works are to be executed.

38. The principles laid down in this and the preceding chapter equally apply to carrying out improvements of gradients on existing roads which, in hilly districts in most parts of the country, have to a great extent been laid down with only one object in view, namely, that of a direct line. The great sacrifice thus entailed, through steep gradients, in the cost of transportation, is a serious one, which could have been avoided in many cases by a little scientific knowledge of what is necessary in laying out a new road, so as to accomplish the greatest amount of work in haulage at the least expenditure of motive power. In other words, a lasting benefit would

have resulted had these roads been properly laid out when constructed, in the form of greater facility for travelling, avoiding wasteful expenditure of power in the conveyance of goods, less wear of horses, and repairs to vehicles, as well as a saving of time. The surface is less damaged by the traffic on roads having easy gradients, and involves less expenditure for maintenance.

39. Improving Gradients on existing Roads.—The following example of a cross-country road is a case in point where had the route followed the proposed line, one horse could, without any great exertion, have hauled an ordinary load, which requires two horses to perform over the existing road at present.

On the plan, fig. 13, Plate II., the existing road, so far as where the steep gradients are situated, is shown at A B, which it will be observed is nearly straight from point to point. On referring to the longitudinal section of this road, fig. 14, Plate II., it will be seen that the gradients are very steep on either side of the first ridge with a valley and ridge beyond. This case, like many others situated in similar circumstances, may be taken as analogous to the road between London and Barnet already mentioned, and as an instance of laying out a road with useless ascents when a subsequent descent must be made. The number of feet actually ascended is most unnecessarily increased when such height once gained is lost again. The improvement referred to is shown on plan, at A, C, B, fig. 13, the length of deviated road compared with the present one being about 180 yards longer. This additional length to be traversed is of little consequence, however, when the improved gradients are taken into consideration. A longitudinal section of the proposed road is shown in fig. 14, Plate II., and also the surface of the existing road is represented on the section by dotted lines.

The proposed new road, after leaving the existing one at A, branches slightly towards the west on a rising gradient of 1 in 38, and attains the ridge of the first hill at C; as the surface of the ground falls considerably between that point and D, it is necessary to introduce a minimum gradient in order not to lose any height already gained. By this means the point D is reached, where, owing to the ground rising somewhat abruptly towards the north, it is necessary to curve the line towards the east, and crossing the existing road at E, is gradually curved backwards till it joins the present road at the point B. The gradients on the deviated line of road, it will be observed, are such that a horse, by a slight effort, could surmount the steepest incline readily, even with what is usually considered a load on a level road. In connection with this subject, it is necessary to bear in mind that a horse can, for a short time, exert an effort two or three times greater than that which he can keep up steadily during a day's work. Steeper ascents for short distances can therefore be surmounted, while excessively steep ones may be overcome oftentimes by the horses voluntarily pursuing a zigzag course in search of an easier gradient.

CHAPTER III.

EARTHWORKS, DRAINAGE, RETAINING WALLS, CULVERTS, BRIDGES, AND PROTECTION OF ROADS.

40. Equalizing Earthworks.—Earthwork, as generally understood, embraces not only the excavation of the looser materials of the earth's crust, but rock also. In selecting the final direction and gradients of a new road, it is obvious that due regard must be observed to equalizing the cuttings and embankments, so that the earth taken from the one may be sufficient to form the other, or, in other words, the earthwork should be redistributed along the line of road. Unnecessarily heavy works are thereby avoided, and the outlay of capital involved is a consideration of greater importance than the mere maintaining of a strictly direct line. In the generality of cases occurring in practice the engineer is obliged, in arriving at this, to resort to a system of approximation; for this purpose the line of road should be divided into several sections, to be treated separately in the first instance, and finally in connection with the adjoining sections.

It is advisable, in many instances, in carrying out the adjustment of the earthworks, owing to the distance apart of the cutting from the embankment on a line of road, to construct the embankment when possible from side-cutting, thus avoiding the great expense necessitated by having to transport the material an excessive distance. In like manner, transferring earth from a cutting situated a considerable distance from an embankment on the line of works, especially when of an unsatisfactory nature, may in some cases be deposited on the adjoining ground contiguous to the works. This method of disposing of the earth from the cuttings is known as forming a spoil-bank.

41. Transverse Balancing.—Transverse balancing in hilly parts, or in sidelong ground, as already indicated, is accomplished by locating the centre line of the road, so that the cutting from the one side will form the embankment on the other. The cost of transport compared with that of excavation and the value of land from which side-cutting is taken, or

spoil-banks are formed, will determine the distance within which the balancing of the earthworks must be established.

42. Side Slopes.—The forming of the side slopes requires considerable attention, so as to ensure stability, and prevent slipping. The resistance to slip arises partly from the friction between the grains composing the soil and partly from their mutual adhesion.

Friction is, however, the only force which can be relied upon for permanent stability, as the adhesion of the earth is destroyed by the action of air and moisture, this being especially the case during alternate frost and thaw. The nature of the soil, its condition as to internal moisture and the atmospheric influence, therefore, combine in fixing the inclination of the side slopes.

43. The slopes of earthwork are generally described in the ratio of the horizontal breadth to the vertical height. The angle of repose, or, as it is generally termed, the natural slope at which different kinds of earth, by friction alone, will remain permanently stable, is shown in the following table given by Professor Rankine in his work on *Civil Engineering*.

TABLE VII.

Natural Slopes of Earths (with horizontal line).

Earth.	Angle of Repose.	Coefficient of Friction.	Customary designation of Natural Slope.
Dry sand, clay, and mixed earth,	from 37° to 21°	0·75 to 0·38	1·33 to 1 to 2·63 to 1
Damp clay,	45°	1·00	1 to 1
Wet clay,	from 17° to 14°	0·31 to 0·25	3·23 to 1 to 4 to 1
Shingle and gravel,	from 48° to 35°	1·11 to 0·70	0·9 to 1 to 1·43 to 1
Peat,	from 45° to 14°	1·00 to 0·25	1 to 1 to 4 to 1

The slopes most frequently adopted for earthwork are those designated $1\frac{1}{2}$ horizontal to 1 perpendicular, and 2 to 1, corresponding to the angles of repose, $33\frac{1}{2}°$ and $26\frac{1}{2}°$ nearly.

44. Rock cuttings, the material of which does not disintegrate on exposure to the action of the weather, may be formed with perpendicular sides, but generally a slope of 1 horizontal to 2 perpendicular is given to admit of free action of the sun's rays on the road surface.

45. For a similar reason the side slopes on the south side of roads in northern latitudes are sometimes made flatter than the natural slope given to that part of the cutting on the north or opposite side. By this arrangement the surface of the roadway is exposed to the action of sun and air, causing rapid evaporation of the moisture on the surface.

46. Stratified soils and rocks, which have a dip to the horizon, are liable to slips caused by one stratum becoming detached by the action of frost or water and sliding on another, the worst combination being that of soils formed of alternating beds of clay and sand.

47. Embankments.—Embankments of any height should be formed with great care. They may be carried out by laying the material from the excavation in successive layers of from 3 to 4 feet in thickness, and thoroughly pounding each layer. This is, however, an expensive process, and seldom resorted to in ordinary works of any extent.

The method usually followed is to run the extreme outsides of the embankment first, and then gradually fill up the centre portion, by which means greater solidity is secured than when the embankment is carried forward and the material tipped from one end only. By this arrangement the layers are formed with an inclination inwards, counteracting, so to speak, as a whole, any tendency to slip outwards. During the construction of an embankment, due consideration must be given to the settlement of the loose or excavated material which takes place. It is advisable to make the height and width of the embankment greater than the dimensions ultimately required; the amount allowed for settlement varies according to the class of material, but may be from one-twelfth to one-fifth of the total height.

It is usual, as a precautionary measure, to form a slight excavation at the tail or toe of the slope to give the material forming the embankment additional stability.

48. Consolidating Embankments.—The compacting of embankments and road beds generally, until the material composing them forms a uniform and unyielding surface, is carried out in the United States and other countries by the use of a horse roller weighing about 3 tons. The roller is about 5 feet wide, and is ribbed or corrugated similar to corduroy. The formation level or foundation of a road is consolidated in this country by the aid of a steam roller. It requires, owing to its weight, very careful handling on newly-formed embankments of any great height. Depressions are made good by the application of material similar to that of which the formation of the road is composed.

49. Embankments on Sidelong Ground.—On sidelong ground different methods are employed in order to secure a solid basis for an embankment sustaining a road. Where the inclination of the natural surface of the ground is not great, and the formation of the road is partly in cutting and partly in embankment, the method of cutting the surface of the ground into steps, shown in fig. 15, is generally adopted. The natural surface of the ground is represented by $a\,b$, the steps or benches are shown at f, f, f, and the formation level at $c\,d$. The best position for these steps is perpendicular to the axis of greatest pressure.

On sloping ground under similar conditions, but with the natural surface

lying at a considerable inclination, the above method of construction will not be sufficiently secure, and recourse must be had to some other means of effecting this.

50. Retaining walls of sufficient thickness, built either dry or with the stones laid in mortar to support the roadway, are constructed for this purpose. These walls may have to be built on either side of the roadway to sustain the embankment on the lower side, and the portion in excavation on the higher part. The wall which sustains the embankment should be built up to the level of the roadway and a parapet or fence wall erected upon it, to protect pedestrian and vehicular traffic against accident. When necessary to erect a wall to form the slope or sustain the ground in excavation, it should be carried up to a height to meet the natural surface of the ground. The arrangement of retaining walls on sidelong cutting is shown at fig. 16, *a b* being the natural surface of the ground. Considering the

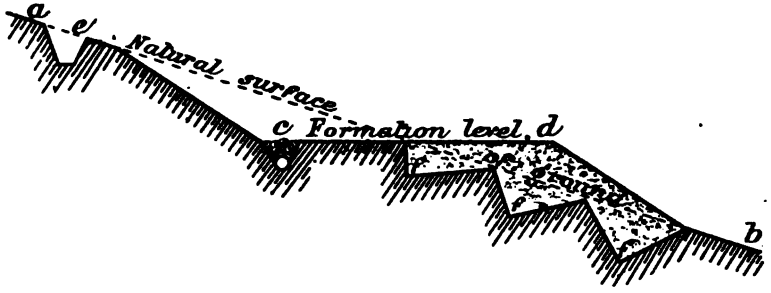


FIG. 15.—Cross-section of a road showing method of stepping adopted in sidelong ground.

inclination of the natural surface of the ground *a b*, it is evident that such a long embankment slope as *d b* would endanger the stability of the roadway. It is necessary, therefore, to secure the solidity of the road in a more permanent manner by the substitution of retaining walls for an embankment on such a slope as that represented in the diagram. Under certain circumstances it might also be advantageous to build a retaining wall at *c*, to retain the part in excavation, as a long slope exposed to the drainage of the higher ground would in time cause the material composing it to be washed on to the road, and in all probability create a landslip. If a footpath is to be formed alongside of a road in sidelong ground it should be placed on the portion embanked, leaving as much as possible of the solid ground for vehicular traffic.

51. **Roads formed over Low-lying or Marshy Ground.**—In crossing plains or marshy ground it is necessary to form the surface of the road well above the general level of the surrounding country in order that it may be kept as dry as possible. This is particularly the case where the line of communication traverses a district subject to inundation. The best method

of accomplishing this is to excavate side trenches at sufficient distances apart on either side of the roadway, from 3 to 4 feet deep, 18 inches to 2 feet wide at bottom, and having side slopes 3 to 1. This excavated material is made use of in raising an embankment between the trenches, so as to elevate the road surface above any possible inundation, and the side ditches will serve to collect the surface water and discharge it to the nearest stream or water-course.

Soft or marshy ground is a difficult as well as an expensive obstacle to overcome in the construction of a new road. It must be borne in mind that laying out a road under these conditions is only undertaken when no other reasonable alternative is possible, such as deviating from a direct line by making a detour even of considerable length. The work can only be accom-

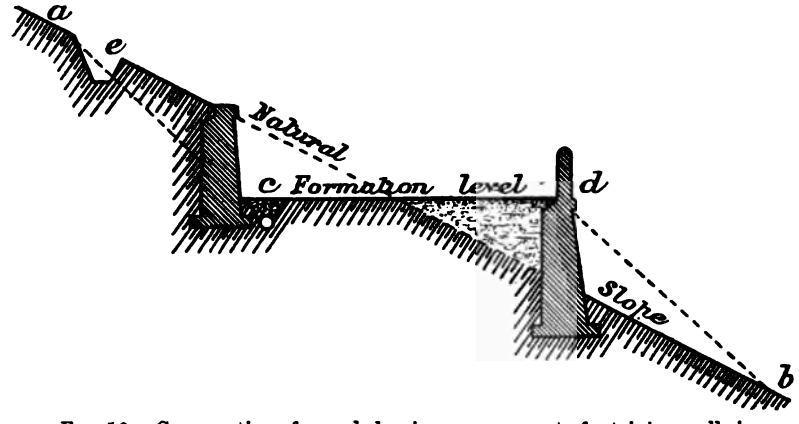


FIG. 16.—Cross-section of a road showing arrangement of retaining walls in sidelong ground.

plished properly by draining the subsoil, so as to consolidate the ground as much as possible, and forming an embankment to carry the roadway. This is effected by excavating a trench in the soft ground to a depth varying with the degree of difficulty to be overcome, and then filling in the trench with stable material. The level part of the excavated portion of the trench is made of a width corresponding to the width of the formation level of the road, while the slopes of the trench should be inclined at the angle of repose of the soft material composing the natural ground. The slope of the stable materials forming the embankment is made to correspond with that of the trench slopes, and as this is much flatter than necessary, a broader foundation and consequently increased stability are secured.

Another method of making soft ground suitable for carrying a roadway is to drive in short piles; this has the effect of consolidating the mass of soft earth. Fascines, hurdles, and dry peat have also been at times employed for a similar purpose with good effect. Should these expedients fail, a bog

or marshy ground may be made secure by tipping sand, gravel, or stones upon it in order to form an embankment which will rest on the hard stratum below the moss, and raising the upper surface to the required level. The slopes of an embankment thus formed assume the same inclination as they would have under ordinary conditions.

52. Half-widths and Extent of Ground required.—When the inclination of the slopes has been determined, the half-widths, or distance on either side of the roadway, may be staked off, and the area of land computed, allowing 6 feet on either side beyond the formation level or the edge of the slope.

53. Finishing Slopes, Drainage.—The slopes of cuttings and embankments should be dressed to regular surfaces with soil from 3 to 6 inches deep and sown with grass seed. This diminishes to a great extent the effect of rain washing or running down the slopes, forming gullies, and helps to prevent any tendency to side-slips. When the slopes are exposed to the action of water they should be covered with dry stone pitching 12 inches thick and of a height sufficient to protect the material of which the embankment is formed.

54. The numerous and diverse nature of circumstances met with in the laying out and construction of roads are such that no definite rules can be laid down to embrace all cases. The engineer will have to consider which form of construction will best suit the particular piece of work undertaken, with a view to economy in carrying out the operations involved, the stability of the works generally, and the subsequent maintenance of the road. In executing the necessary work in cuttings and embankments, level pegs are fixed indicating the depth or height of formation at convenient points, so that the workmen are enabled, by the use of boning rods or cross heads, to keep the intermediate position of the earthwork at its proper level. Important points, such as where a curve joins a straight line, should be transferred during the progress of the works by means of pilot pegs. This is accomplished by ranging a straight line from the point in question, fixing two pegs clear of the line of works and measuring the distance apart of these; the tangent point can then be readily re-established after the earthwork is completed. A similar operation should be carried out where important structures are to be erected.

The volume or cubical quantity of a piece of earthwork is ascertained by computing the area of a series of cross-sections of known distances apart, and the quantities obtained are stated in cubic yards.

55. Drainage.—The drainage of roads is of two kinds, namely, surface and subsoil. It is one of the most important operations in connection with the construction of a road, as on its efficiency the subsequent maintenance of the surface will greatly depend. The slopes in cuttings on sidelong ground are generally the most troublesome, and great pains should

be taken in order to thoroughly intercept, from the rising ground, any flow or filtering of water towards the road bed. This is readily accomplished by forming catch-water ditches or drains on the uphill side of the cutting a few feet back from the crest of the slope or point where the excavation joins the natural surface of the ground, as at *e*, figs. 15 and 16. These, if possible, should be carried to the most convenient water-courses; but where the surface of the ground is such that a sufficient fall cannot be obtained unless at great expense in cutting and laying drain pipes, the water may be conveyed down the slope to the side channel or covered drain near the formation level as at *c*, fig. 15. When open conduits are formed for this purpose, the slope should be protected by forming a rough pavement, as the soil cannot withstand the action of the water on the steep slope generally given to cuttings. This object, however, is better attained by laying stoneware drain pipes in the slope 18 inches below the surface. The slopes of cuttings may, when necessary, be further protected by laying drains in a trench 18 inches deep, cut in an oblique direction up the slope, filling the space up to the surface with stones, and connecting them to the drain at the bottom of the cutting. Where springs occur, the water should be carried away by laying the pipes to the side drains, or by some other effective means.

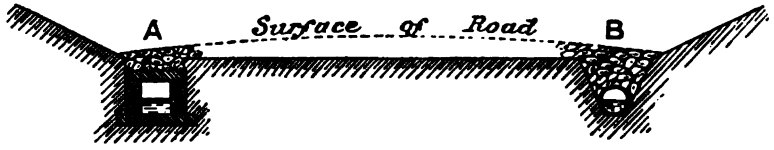


FIG. 17.—Cross-section showing side drains at formation level of road.

Drains should also be constructed at the foot of a slope in cuttings, varying in depth from 18 inches to 3 feet, according to circumstances. These may be built with either brick or stone; a less expensive method, however, and much more effective and durable, is made by laying salt-glazed plain pipes in the trench and filling the space up to the surface with broken stones, which must be free from dirt, to a height of 6 inches above the formation level of the road. Fig. 17 shows the two methods of construction, that at A being built of stone, while the drain at B is formed of salt-glazed pipes, the space above, in either case, being filled in with small stones.

56. The lower half of drain pipes may be surrounded with clay to prevent any water lying around them. This precaution should be adopted when the drain has but a small inclination, as the water in the pipe will be discharged more quickly and prevent the lower portion of the ground becoming waterlogged.

57. In sidelong ground, and on level tracts of country, the side ditches should be formed before the cuttings are excavated and the embankments formed, as greater stability will be ensured by the ground being in a dry state.

58. The drainage of embankments does not require such extensive operations as those necessary in cuttings. The water from the surface of the road should be carried by the water tables or side channels to suitable points where it can be conveyed down the slopes in open troughs. It is usual to form an open ditch on either side, nearly parallel to the axis of the road and at the tail of the embankment, to collect and convey the surface water from the road and slopes of the embankment to the nearest water-course or point of discharge. Where a falling gradient in a cutting adjoins an embankment, a similar course is pursued when such cannot be diverted, great care being exercised to have the conduit of sufficient capacity to convey all the water which will collect in the cutting under the most unfavourable circumstances. On sidelong ground it is seldom necessary to make an opening at the toe of an embankment, the natural slope of the ground being in most cases sufficient to carry away the limited amount of water likely to collect there. All drains and open ditches should have sufficient capacity and acclivity to receive and convey away quickly all the water that may find its way into them; this will also be influenced by the nature of the soil in which they are placed. When a footpath exists at one or both sides of a road, the surface drainage collecting in the side channels is conveyed by pipes laid under them to the ditches, or drains, or on to the surface of the ground on the field side of the footpath.

59. **Subsoil Drainage.**—The drainage of the subsoil provides for the removal of any water found in the soil immediately under the road covering in cuttings and on level tracts of country. This is an essential and important requirement in road construction, and on the efficient state of repair in which the subsoil drainage is maintained, will the cost of keeping the surface of a road in good repair depend.

60. The materials composing a road covering placed on a naturally wet, retentive, or undrained soil, such as clay and kindred earths, will go quickly to pieces by the traffic passing over it or by the action of thaw succeeding frost. The combined effect of these influences, which converting the whole coating material into a disintegrated mass, is simply ruinous.

Soils.—Soils of a siliceous and calcareous nature, and rocks generally, do not present any great difficulty, as their porous nature assists in securing a dry and solid foundation.

61. The side drains in cuttings, and the open ditches on the level portions of a road, will, as a rule, be sufficient for this purpose, even where the roadway is of a great width.

It is the argillaceous and allied soils which require careful treatment, as, being of a retentive nature, they become very unstable when in contact with water and the action of frost. The drainage of such soils may be effected by forming transverse or cross drains in the form of the letter V, as shown at *b*, *a*, *b*, fig. 18.

These drains should consist of salt-glazed plain pipes 2 to 3 inches in diameter, laid about 15 to 18 inches below the formation level at centre, and properly connected to the side drains. The junction is preferably made at the highest point of the pipe in the side drain, and an opening

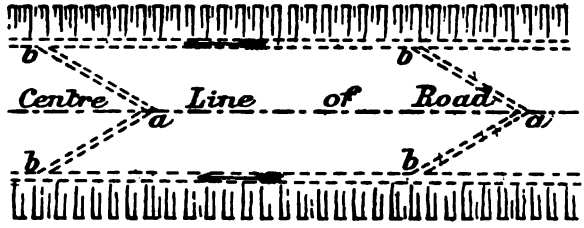


FIG. 18.—Diagram showing arrangement of subsoil drains in retentive soils.

formed of dry stone built, over where they join, up to formation level for inspection from time to time. Ordinary field or agricultural drain pipes are sometimes used, but being porous are liable to injury by frost, and cause great inconvenience and damage by breaking, as well as a temporary derangement of the drainage of the subsoil, which is sometimes difficult to locate. The trenches should be filled up with clean gravel or small stones, free from all clay or other soft matter, care being taken to hand-pack the material round the joints of the pipes.

The diagram at fig. 19 shows a cross-section of a road with the mitre

FIG. 19.—Cross-section of road showing mitre drains.

drains at *a*, and joining the side drains at *b*, and a cross-section of the mitre or transverse drain is shown at fig. 20. It is not essential that these cross drains should have a great fall; the purpose may be properly served by giving them an inclination of 1 in 50. The nature of the soil will afford the means of determining at what distance apart these cross or mitre drains should be placed; this may vary from 15 feet in very wet situations, increasing in distance to 30 or even to 50 feet where the subsoil is of a drier and less retentive nature. The surface water from the roadway is collected in the side channels and conveyed, where the level of the roadway is at or near the natural surface of the ground, to the ditches, by outlets cut at certain intervals on either side of the roadway. Where footpaths exist alongside of a road, drain pipes are laid across and underneath the footpath at convenient points, the outer edge of

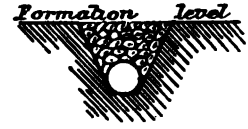


FIG. 20.—Cross-section of mitre drain.

these pipes at the roadside being protected from damage by passing vehicles, by fixing a stone at each side of the drain pipe well into the ground, and covering them with a flat stone projecting 2 inches beyond the conduit, but in line with the edge of the footpath.

62. On embankments, especially in sidelong ground, the surface water, as already mentioned, is conveyed to the open ditches in wooden troughs, creosoted, or tarred and sanded, and fixed in the slopes. This method, although satisfactory in many cases, is not to be recommended as a permanent arrangement; a drain constructed of salt-glazed faucet and spigot pipes laid in clay puddle, or covered with concrete and finished at the toe of the slope with masonry, is required to keep it in position.

It is necessary to exercise great care in carrying out the work by placing puddle around, or otherwise protecting the joints, so as to ensure that no water will be permitted to percolate through the earthwork, which, if allowed, would in all probability result in considerable damage being done to the embankments.

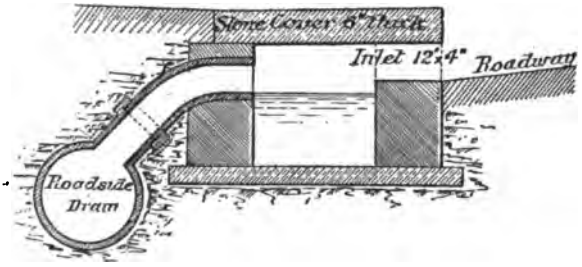


FIG. 21.—Diagram showing sand trap.

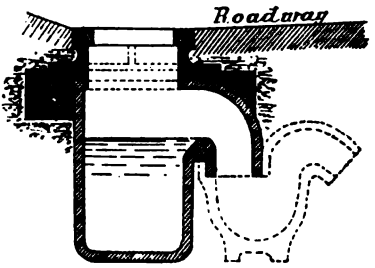


FIG. 22.—Diagram showing sand trap.

63. Drains in Cuttings and Different Arrangements of Sand Traps or Gullies.—In cuttings, the system followed is somewhat different, being generally effected in the following manner. The side drains are utilized as a means for the disposal of the surface water which, in the first instance, enters a gully or sand trap, the overflow from the latter being connected to the side drain. The use of a sand trap, especially on a road having a considerable fall longitudinally, is to intercept any heavy matter or detritus which would otherwise gain entrance to the drain, and in course of time, by repeated accumulations, cause the drain to become choked. The simplest and cheapest form of sand trap is represented at fig. 21, built of brickwork with suitable covers, and at fig. 22, which is made either of earthenware or cast iron. Stoneware gullies are, as a rule, liable to damage by the passing traffic, and should be placed in the least exposed situations, or clear of the water channels. This form of trap is also made in detached portions, the basin or stoneware part forming the trap, with a cast iron cover and grating

fixed on the top. It is claimed that this form of gully trap is unbreakable under the heaviest class of traffic. Sand or gully traps are also made of cast iron in one piece and in different sizes to suit different localities. The gratings are detachable, and, on the whole, this class of trap is the best possible to adopt, and serves most effectively the purpose intended. This class of gully or sand trap is shown in fig. 23.

When one road crosses another, it often happens that two or more drains have to be connected to one gully or sand trap. This is most conveniently accomplished by building it of stone or brickwork, with a pavement or concrete floor of a sufficient area to embrace the side walls and form a foundation. The floor should be at least 18 inches below the level of the outlet pipe, to collect the detritus or heavy matter. If the trap be built of brick the walls need not exceed 9 inches in thickness, unless the drain is exceptionally deep, when it will be advisable to increase the thickness of the walls. A convenient size of trap for such a situation, with three inlet pipes, is shown in fig. 24.

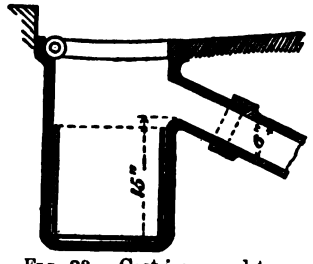


FIG. 23.—Cast iron sand trap or gully.

The brickwork is brought up to within a few inches of the level of the water table, the covering and grating being either of cast iron fitted properly into the brickwork, or it may be finished with a stone cover, and a wrought iron hinged grating dished out to admit of the water from the channels passing freely into the sand trap. A space nearly equal in size to the iron grating requires to be cut out in the centre of the stone cover, provision being made for properly fixing the grating to it by means of batts.

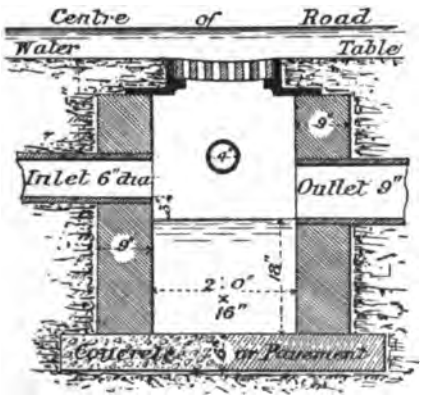


FIG. 24.—Sand trap with three inlets.

These sand traps should be cleaned out periodically, and also immediately after a heavy fall of rain, so that the road detritus and sand may be prevented from entering the outlet pipe. The inlet pipe or pipes should be placed at a higher level than the outlet pipe, to ensure a rapid discharge; 2 to 3 inches being quite sufficient for this purpose.

64. When it is necessary to lay a drain under a road, the work should be of a substantial nature, so as to avoid any possible derangement of the drainage, and probable damage to those using the road, by its failure.

Drains for conveying water under a road should be built of good stone and bedded in cement, with paved floor and substantial covers. Salt-glazed or earthenware spigot and faucet pipes are also employed; these should be cement-jointed, and if necessary protected with a layer of concrete under and round the outside of pipe.

65. Retaining Walls.—Retaining walls are structures in masonry, laid dry or in mortar, designed in various forms to support the sides of roads on hillsides, or when land is not available for forming side slopes beyond the formation level of the road. Where building materials of sufficient size can be procured, the retaining walls may be built of stones laid dry; when, however, the materials for this purpose are not large, flat-bedded stones, it is advisable to use mortar in building the walls.

With suitable material, drystone retaining walls are well adapted for road work, on account of their self-draining properties and their cheapness. The outside face is generally built with a batter, either straight or curved, varying from 1 in 8 inches to 1 in 12 inches; any excess of batter greater than 1 in 6 should be avoided where mortar is used, as the action of the rain tends to destroy the joints by washing it out, and affords lodgment for seeds of vegetation, the roots of which penetrate the wall and injuriously affect the adhesion between the mortar and stone. Retaining walls built with stones and mortar are rendered more secure from the effects of water by having drystone packing, usually 12 inches thick, set by hand at the back of and between the wall and earthwork. Weeping holes, formed of 2- or 3-inch pipes, should be built into the wall at different levels; but especially at the base of the wall, and at a distance of from two to four yards apart, according to the nature of the soil and the dip of the strata.

The top of the retaining walls should be properly finished and protected by a coping of stone, close jointed, to prevent rain finding its way into the body of the wall.

Drystone retaining walls are generally finished on the top with a sod coping laid in two rows; when properly carried out, this method of protecting the walls suits the purpose exceedingly well. The profile or cross-section, and the thickness to which retaining walls are built, vary according to their position relative to the adjoining work and the nature of the material to be retained.

The foundations of retaining walls are subject to considerable and unequally-distributed pressures. They should be of a width or area sufficient to bear safely the pressure which they have to sustain according to the nature of the ground on which they are placed. A suitable drain should be laid at the base in front of a retaining wall to collect and convey any water escaping from behind the wall. Ordinary foundations may be classed under the following heads: (1) On material, the stability of which is not impaired by saturation with water, such as rock; (2) on firm earth, sand, gravel, and

hard clay; and (3) on soft earth. The area of the foundations may be increased to any desired extent by forming steps beyond the thickness of the wall proper, so that the weight of the structure may be distributed over a large surface. Rock of a moderately hard description will bear safely 9 tons per square foot; firm earth 1 ton to 1½ tons; soft earth, on the other hand, is only capable of bearing a very limited load; and to ensure safety the ground should be well drained, the soft earth removed by cutting a trench and substituting stable material, such as sand or concrete. In extreme cases it is necessary to drive short piles into the ground to compress and consolidate the soil, on which a platform is fixed, the heads of the piles being surrounded with concrete. The depth to which a foundation should be excavated must be such that it will be below the disintegrating influence of frost: 3 to 4 feet is considered a safe depth in Britain, while in countries subject to severe and long-continued frost a depth of from 4 to 6 feet is necessary.

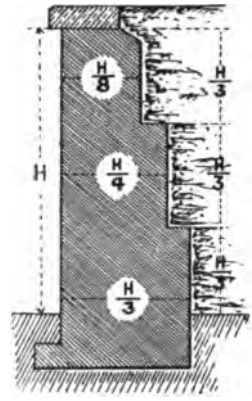


FIG. 25.—Section of retaining wall.

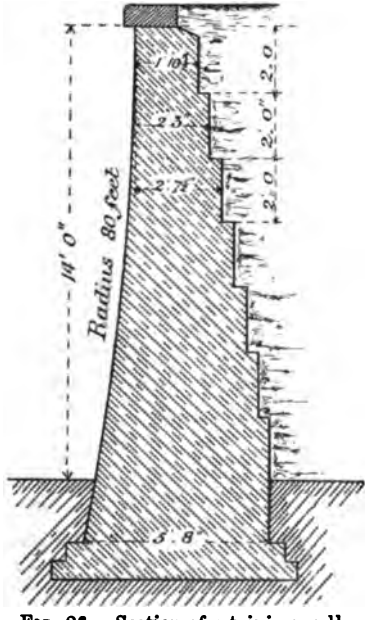


FIG. 26.—Section of retaining wall (built of brickwork).

66. Dimensions of Retaining Walls.—In determining the proportions to be given to retaining walls, the engineer is guided by the experiments, and from the successful results attained in existing structures which have withstood for a considerable period of time all the usual causes of destructibility. From these examples many practical rules have been deduced for the design of stable and economical retaining walls, as well as for the thickness of abutments and arches of bridges and culverts.

For retaining walls 6 to 10 feet high a thickness of one-fourth of the height of the wall above the natural ground is generally allowed. In large structures built of masonry, the height of the wall above the ground level is divided into offsets, and the thickness is varied from one-third to one-eighth of the total height, as shown in fig. 25.

The following dimensions are extensively used in building retaining

walls with brick, viz., the thickness at the top of the wall is made 1 foot 10½ inches, and at every fifth course downwards the thickness is increased by half a brick, the face of the wall being built with a batter of 1 in 6 to 1 in 8, which is generally curved as shown at fig. 26. In retaining walls constructed of stone without mortar, the thickness may vary from one-third to one-half the height, the face being built perpendicular or with but a slight batter, to avoid as much as possible rain-water being carried inwards to the earth backing, which would occur if the joints were inclined by giving the face an excessive batter. Should it be found necessary to batter the face of a wall built dry, the difficulty alluded to may be obviated by pointing the outside joints of the wall. Trautwine's rule for a retaining wall, which sustains a backing of sand, gravel, or earth, level with its top, is, that the thickness of the wall should be not less than that stated in the following table, when the foundations are about 3 feet deep, the backing being deposited loosely, as when tipped from carts, wagons, etc., and the batter not exceeding 1½ inches to a foot.

TABLE VIII.

Wall of cut stone or first class large-ranged rubble in mortar, ...	·35	of its entire	vertical height.
Wall of good common scabbled mortar rubble or brick,	·4	do.	do.
Wall of well-scabbled dry rubble, ...	·5	do.	do.

The effect of stepping the back of a wall increases the friction of the earth against it, giving increased stability, so that when the thickness has been proportioned with a vertical back by Trautwine's rule, it may be converted into one having offsets, which has the advantage of greater resistance to overturning, and yet contains no more material. The method of arriving at this is as follows:—From the point *c*, fig. 27, half the height of *a b*, draw a line from *d* one-half of the thickness of the wall at the top *a a*, through *c* to *e*, and from the latter draw the vertical line *e f*; divide *d f* into any number of equal parts, for instance three, and produce vertical lines to the base *b e*; then divide *f e* into one more equal part than *f d* contains, and draw horizontal lines crossing the vertical ones. From the points of division draw the line forming the offsets as shown in the figure.

67. Surcharged Retaining Walls.—When a retaining wall is surcharged, that is, retains a bank which slopes backward to a higher level than the top of the wall, the thickness, according to the foregoing rules, must be increased.

This class of wall, fig. 28, is principally made use of in cuttings, but in some cases walls of this description are built to retain the toe of an embankment. The following table, given by Molesworth, shows how the thickness of a surcharged wall of rectangular shape may be arrived at.

The height Y is substituted for H, in fig. 25, or height of the wall from ground level, and is the perpendicular at the end of a line L equal to H, measured along the slope to be retained. The value of Y for various slopes is as follows:—

TABLE.

Y = 1·71 H.	in slopes	1 to 1
,, = 1·55 H.	,,	1½ to 1
,, = 1·45 H.	,,	2 to 1
,, = 1·3 H.	,,	3 to 1
,, = 1·24 H.	,,	4 to 1

68. Counterforts.—Counterforts are projections of masonry at the back of a wall, built at intervals, and of a rectangular shape; they are intro-

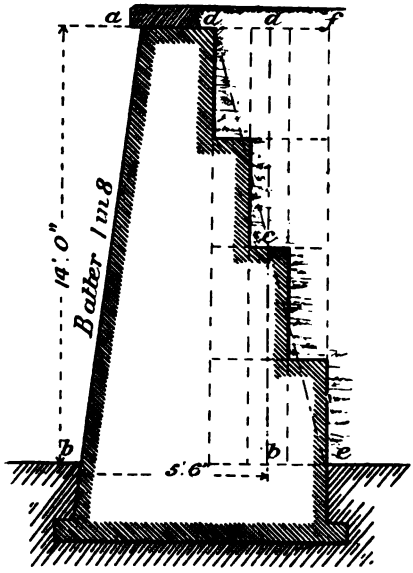


FIG. 27.—Section of retaining wall, proportioned by Trautwine's rule.

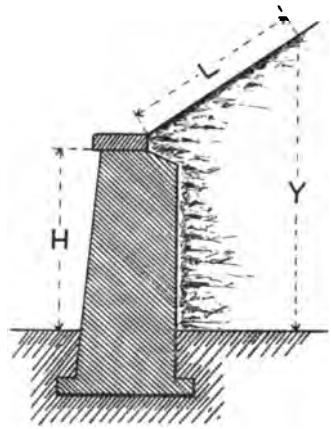


FIG. 28.—Section of surcharged wall.

duced to increase by their weight the stability of retaining walls, but this depends on the efficient manner in which these are bonded to the retaining wall at their junction.

69. The result of the experience of Sir B. Baker in connection with the building of retaining walls may be given. "In ground of an average character the thickness of retaining walls should be one-third of the height from the top of the footings. A wall quarter of the height in thickness and battering 1 to 2 inches per foot on the face possesses sufficient stability when the backing and foundations are both favourable." He also states that "under no ordinary conditions of surcharge or heavy backing is it necessary

to make a retaining wall on a solid foundation more than double the above or half of the height in thickness."

70. Breast Walls.—Breast or revetment walls are very useful in cuttings. They are generally employed to act as a covering for earth which has sufficient stability to stand vertically alone. They need not be of great thickness, provided they are of sufficient strength to resist their own weight; it is advisable to raise them above the level of the ground where the slope joins the wall, in order to prevent stones and earth, which may become detached by the action of the weather, from falling on the roadway.

71. Culverts.—Culverts are necessary to carry a roadway over a water-course, and for conveying the surface water from the road, as also that from the drains in cuttings and open ditches running parallel to the axis of the road, which are conveyed and discharged into the stream.

72. Waterway of Culverts.—Care should be exercised in determining the waterway necessary for culverts under varying conditions, so that the opening may be built slightly in excess of the actual requirements. If a culvert is built too small, it is liable, during floods, to be washed away, along with possibly a considerable portion of the embankment, causing interruption of traffic and heavy cost for repairs.

Culverts of unnecessarily large dimensions involve a needless increase in the cost of construction. The area of waterway required depends principally on the following considerations:—

The maximum rainfall during a severe storm.

The nature and condition of the soil, and the character and inclination of the surface.

The area to be drained, with special regard to the number and position of the branch streams which join that under consideration.

The annual recorded rainfall for any particular district does not aid the engineer to any extent. An average fall for a given period does not necessarily mean that a fixed quantity has fallen each day; it is possible that the total recorded amount in a certain time may have fallen on one particular day, and probably only during a few hours of that day. A thaw and heavy rain succeeding a fall of snow when the ground is frozen, and a heavy rainfall during a thunderstorm, are certainly the worst possible conditions to be provided for in practice.

The hard nature of the surface of the ground under the former conditions precludes any moisture being absorbed by the soil, and this circumstance, combined with the falling rain and melting snow, increase the difficulty of calculating the area of waterway necessary in any particular case. Data of a more or less valuable nature may be obtained by observing the flood-mark of a stream where it is confined within its banks; and by taking a cross-section of the stream the actual area may be computed, from which it is possible to determine with a reasonable degree of accuracy the necessary area

of waterway. Should any other culvert be built over the same stream within a reasonable distance of the proposed crossing, the area of the existing opening should be measured, which will guide the engineer, to a certain extent, in determining what waterway will be necessary. The evidence also of local parties when available may likewise be of great assistance.

73. Materials used in Building Culverts.—Culverts may be constructed of stone, brick, concrete, iron pipes, trough decking on stone or brick abutments, or of salt-glazed or earthenware pipes. The simplest form in which a conduit built of stone can be made is shown in fig. 29. When suitable material is plentiful, this form of conduit is extensively employed. This is, however, an expensive method of construction, when high embankments are formed over the conduit, as, owing to the great weight, large covers of considerable strength are necessary, varying in thickness up to 12 inches. The side walls also require to be built of dressed stone, as the water flowing in the conduit would eventually find its way through the joints, if inferior masonry was used, and possibly wash away the earth backing by being thus softened. This may result in the failure of the structure and consequent stoppage of the traffic, as well as cause accidents, involving the authorities in considerable expense. When of a small size, and therefore difficult to get at, repairs cannot be carried out without stripping the material off the road. Experience of the maintenance of roads clearly indicates that conduits built of ordinary rubble, and with covers of insufficient strength, combined with the inferior quality of the stones often employed, cause great trouble and expense for repairs.

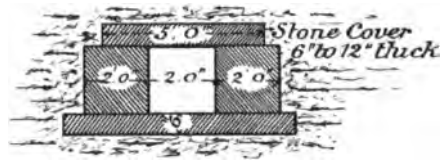
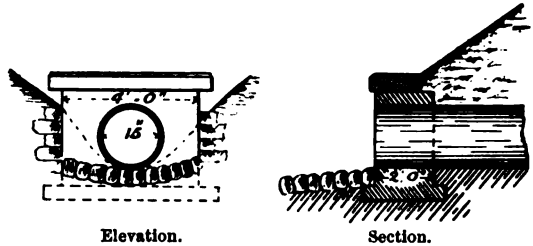


FIG. 29.—Section of conduit built with stone.

74. Salt-glazed or earthenware pipes are now generally made use of for conveying small streams under a road, and are a reliable substitute for the class of conduit just described, providing they are properly laid and jointed and the sides and top of the trench are filled in with suitable material. These drain pipes vary in size up to 24 inches in diameter. They can be laid in position quickly, and are comparatively less expensive than masonry conduits of a similar capacity. Two or more lines of earthenware pipes may be laid alongside of each other when the capacity of one is insufficient. The inlet and outlet ends of the smaller-sized pipes should be protected at the toe of the embankment by building round the outside of pipe flat-bedded stones finished with a sod cope on top. The large-sized class of earthenware pipes are generally protected by forming a pitched slope or wing-wall to retain the embankment in position, and likewise to assist in directing the current of water into the culvert on the up-stream side of road.

In laying these pipes care should be taken to ensure a straight line being preserved, and that the outside joints are properly filled and finished with cement; the inside joints also should be pointed when possible, and thoroughly wiped to remove any projecting particles of cement, and lessen the chance of obstruction. The trench should be filled up under and round the body of the pipes with material free from stones, such as sand, furnace ashes, or similar material, the whole being well punned. When earthenware pipes are situated under a high embankment, it is necessary to strengthen them by placing concrete under and around the outside



Elevation. Section.

FIGS. 30, 31.—15-inch stoneware pipe drain or conduit.

of the pipes. The upper portion of the pipes should, as a rule, never be less than 2 feet below the surface of the road. Instances occur, however, where the conduit pipe has to be laid only one foot below the road surface in order to gain a sufficient fall, and in such cases the pipes must be bedded in and covered with fine concrete. This method should be avoided, if at all possible; but if it cannot be so, the expedient of raising the road level should be adopted, which is an expensive alternative. The outlet or tail-end of conduits should have a sufficient fall, so as to discharge the water quickly, and prevent back-

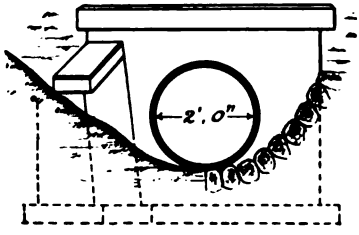


FIG. 32.—End elevation of 2 feet single stoneware conduit.

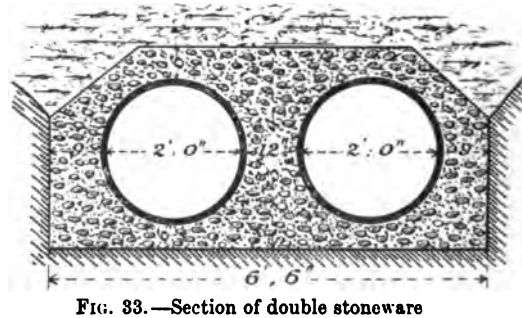


FIG. 33.—Section of double stoneware pipe conduit.

water reaching the pipes. The freezing of water in the pipes, when such a condition exists, tends to destroy them, so that a proper inclination for both the pipes and the outlet of the stream is imperative.

75. The diagrams, figs. 30, 31, 32, and 33, show the method of construction adopted with earthenware pipes described in the preceding paragraphs.

76. Iron pipes are, under certain conditions, a very useful substitute for earthenware pipes and conduits built of stone or brick.

When the foundation is in soft material, a bed of concrete is formed, varying in thickness from 9 inches to 3 feet, according to the size of pipes and the solidity necessary to ensure stability. The joints when of spigot and faucet should be caulked; those having flanges should be bolted together, and any open spaces filled in with cement. The filling or backing should be carefully rammed to prevent the water forming a channel along the outside; the ends should also be protected by wing-walls or pitched slopes similar to the practice adopted in the case of earthenware pipes. The space between the wing-walls at either end should be pitched where any scouring action of the stream when in flood is anticipated, as by so doing the possibility of the foundations of the wing-walls being undermined is prevented, especially at the inlet end.

77. **Arched Culverts.**—It is more economical to build stone or brick-arched culverts when the waterway of a stream necessitates a span of over 5 feet. The arch may take the form of a semicircle, segment of a curved ellipse, or compound curve having different radii. The latter two forms are seldom employed in culverts of small span, that of the segmental arch being generally made use of. By adopting a flat arch, the embankment forming the approach to and over the stream may be reduced in height below what would be required if a semicircular arch were constructed.

78. The small convexity or rise of arch in relation to the span adopted at times in practice presents a weakness, while the horizontal thrust on the abutments, inseparable from this form of arch, is very great.

79. The semicircle should always be adopted in small spans, and whenever possible, in those of moderate span, as this class of arch offers advantages in simplicity of form, great strength, and small lateral thrust.

80. The employment of steel trough decking for culverts has of late years been greatly advocated and applied in practice; they present a form of great strength, and can be erected expeditiously. The necessity for making an embankment in the case of arches is to a great extent, if not entirely, avoided by adopting this method of construction. Steel trough decking of a light section suitable for small spans, such as that adopted in the building of culverts, is manufactured for spans of from 4 to 10 feet, the weight of which is from 20 lbs. per square foot upwards.

81. The depth or thickness of arch stones for culverts depends upon the span, the form of the arch, and the class and quality of material employed in its construction. These remarks also apply in a measure to the thickness to be given to abutments, which will be treated under *Bridges*.

82. Figs. 34, 35, and 36 show the different forms of construction usually adopted and described in the preceding paragraphs. Fig. 34 represents a cross-

section of a 6-feet culvert built of brickwork or concrete, with semicircular arch and an invert, the finished road level being shown 2 feet above the arch. When the bed of the stream has a considerable declivity, and there

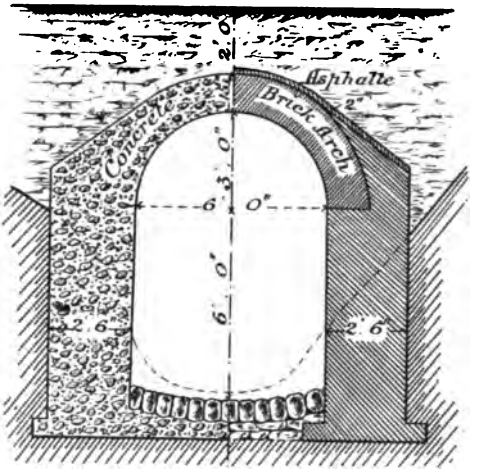


FIG. 34.—Section of 6-feet culvert built with brickwork or concrete.

is consequently a risk of wearing away of the bed during freshets, an invert between the abutments should be provided. The space between the wing-walls, and for a distance along the bed of the stream beyond the newels, should also be pitched to prevent the undermining of the structure.

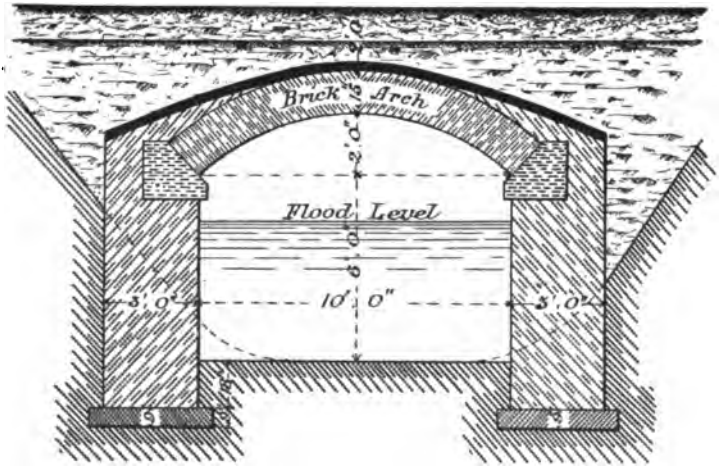


FIG. 35.—Section of 10-feet culvert built with brickwork.

Fig. 35 shows a culvert built of brickwork, the span being 10 feet, and having a segmental form of arch with a rise or versed sine of one-fifth the span.

This arrangement admits of a reduction in the height of the embankment in forming a road compared with a semicircular arch. The stream is assumed to have a gentle current, and the bed not liable to be scoured or worn by freshets. It will also be observed that a springer course of stones is introduced, which affords a more solid and efficient means of starting the building of the arch than would be possible by forming the skew-back with bricks alone.

Fig. 36 shows the principle of steel trough decking applied to culverts, where the raising of an embankment would be necessary if a semicircular arch were adopted. The general arrangement is shown in the illustration, the trough decking occupying a depth of only 8 inches, the space between the ridges being filled with concrete, and the metalling applied to a thickness of 12 inches or an inclusive depth of 20 inches from the under side of beams to the finished surface of the road. With a semicircular arch the finished surface of the metalling would be at least 10 feet 9 inches above the belt or springer course: whereas, using the trough decking, there is a saving of 9 feet of unnecessary embankment, at the site of the structure, and which, if carried out, might cost from £50 to £200.

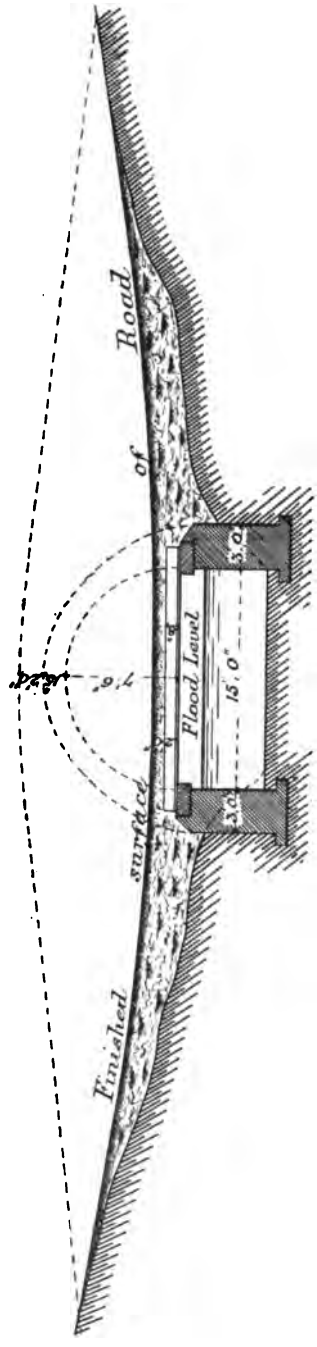


FIG. 36.—Section of 15 ft. culvert and approaches, showing relative levels of road with semi-circular arch and with trough decking.

83. It is advisable to construct catch-pits at the entrance to all drains and culverts in localities where, during a heavy rainfall, there is any likelihood of débris or boulders being washed down the stream. They should be about 3 feet deep, and of the full width of the water-course, and be faced with stones built dry or in lime mortar.

84. Bridges.—Bridge designing and building is a very extensive subject,

and embraces the selection and disposition of various materials under different circumstances.

In a work on road making the leading features necessary to be observed in the erection of ordinary structures can only be touched upon. The author refers his readers for further information to the many valuable works published specially on this subject.

85. Materials used for Building Bridges.—Bridges may be built of stone, brick, concrete, cast iron, or steel; or a combined structure of masonry and steel girders may be adopted. Wooden bridges are sometimes erected in localities where timber is available, but generally these are of a temporary nature, and do duty until permanent structures are substituted.

86. Selecting Sites for Bridges.—The selection of a site for a bridge, unless it is predetermined by a line of road which cannot be changed, should be one which affords the greatest security for the foundations, and is otherwise the fittest for economical construction. The centre-line of the bridge should be, if possible, set out perpendicularly to the direction of the flow, and on a straight part of the stream or river to be crossed. Where the locality does not admit of crossing at right angles, the bridge assumes an oblique direction, which, besides adding to the difficulties of construction, greatly increases the cost of erection. When the width of the river to be bridged is great, it may be advantageous to divide the opening into bays by the erection of piers. The position of these must be parallel to the flow of the stream, otherwise the faces of the piers would be exposed to the effects of the water striking against them obliquely; they should be further protected by cut-waters or starlings in order to ward off any floating material such as ice or timber.

87. Waterway of Rivers.—As the area of the waterway will be to a certain extent reduced if piers are erected in mid-stream, provision should be made for this by increasing the total width of opening between the abutments, the object aimed at being to maintain the original force and direction of the current. If the cross-section is diminished it will cause an amount of damming back of the water, which, when it rises to a certain height, will increase the velocity. This may cause damage by flooding the adjoining land, or the bed of the stream may suffer by being worn away. On the other hand, a greatly enlarged cross-section will have the effect of decreasing the current, and causing the bed of the stream to become silted up with deposits from the higher reaches.

What may naturally be expected under such circumstances is the formation of banks, and should these accumulate to any extent, a diminished area or cross-section is the result.

With a series of bays, however, it is possible that only a few of these may be passing the water of the stream in its normal condition. The increased currents induced by the alteration of the bed of the stream will

have, during floods, a tendency to scour the bottom, and may eventually prove destructive to the structure by undermining the foundations.

88. Nature of Material of Foundations.—Before deciding on the design of a bridge, it is necessary to thoroughly examine the nature of the material on which the foundation of the structure will rest. The usual method of ascertaining this is by sinking trial-pits to a suitable depth, or by boring, and from the results obtained the class of foundation necessary may be determined. The nature of the different soils in connection with foundations are generally divided into three classes.

The first, or incompressible material composing the strata, includes rock and such other material the stability of which is not impaired when saturated by water.

The second class embraces such material as compact stony soils, dry gravel and sharp sand.

The third class includes all materials which are compressible or spread laterally under pressure, such as ordinary clay, the common earths, soft sand and marshy soils, which are usually in a more or less compact state, and sometimes in a semi-fluid condition.

On a foundation of rock the bed is prepared by levelling its surface, and removing all loose and decayed pieces, reducing all projecting points and filling up all hollows with flat rubble, masonry, or concrete.

Where the stratum composing the rock dips, or inclines to the horizon, it should be stepped, all inequalities being filled in with concrete. The surfaces thus prepared should be perpendicular to the direction of the pressure which the foundation has to sustain, and the courses composing such foundation should have an area sufficient to bear that pressure with safety.

89. Safe Load on Foundations.—The safe load allowed on foundations of the first class ought not to exceed one-eighth of the pressure which would crush it. For general purposes this may be reckoned at 9 tons per square foot on rock of moderate hardness, and 2 tons per square foot on soft sandstone; while rock equal in strength to good cement concrete can safely sustain a load of 3 tons on the square foot.

Foundations on the second class of materials have considerable frictional stability when the stratum is not affected by being saturated with water. These must be excavated to such a depth that the structure will rest on ground not likely to be impaired by the disintegrating effects of frost which has been pointed out under the article on culverts. The safe load or greatest pressure permitted in practice on soils for foundations of this class is generally from 1 ton to 1·5 tons per square foot. The foundation courses, or footings, are usually spread out to a considerable extent beyond the ordinary thickness of the walls they sustain, such breadth being as a rule made $1\frac{1}{2}$ and 2 times that thickness in gravel and on hard clay and sand respectively.

Foundations on materials of the third class present difficulties of a varying nature. The precautions necessary to obtain a safe foundation require in many instances special treatment, involving a correspondingly greater expenditure. On the firmer soils of this class, the usual practice is to lay a bed of concrete varying in depth from 3 to 6 feet, making the breadth of base as wide as practicable. On material which is not homogeneous or is liable to lateral yielding, stability is promoted by enclosing the area of the foundation by sheet piles from 5 to 10 feet long. The soft material composing the soil is then excavated to the required depth, and sand or other suitable material of a stable character spread in layers and punned; this forms to a certain extent a natural sand foundation.

90. The filling material, so as to ensure greater stability, may be composed of concrete, and although in certain cases this may appear an excess of precaution, it is, nevertheless, advisable to adopt this method of construction when the soil is not of a uniformly compressible nature.

It is necessary, in order to maintain the foundations in a stable condition, that all water in close proximity be got rid of by draining.

91. Timber Platform Foundations.—Timber platforms have been used as an expedient, where the soil forming the foundation was of a wet and soft description, with a view to distribute the weight of the structure uniformly on its surface. This method of construction consists in the laying of heavy timbers at some distance apart longitudinally and crosswise, forming a grating, the spaces between the timbers being filled with material of a stable nature, or with concrete; the whole being surmounted with planks 3 or 4 inches thick fixed to the timbers and upon which the building rests.

Another method of forming timber platforms is to lay several tiers of planks well spiked together. The durability of these foundations is dependent on their being constantly in a wet condition.

92. Piling Foundations.—Where the nature of the stratum is so soft or unstable that any of the foregoing methods cannot be applied, recourse must be had to piling. Bearing-piles of varying length and from 9 to 18 inches in diameter are driven into the soil to sustain the superincumbent weight. These are spaced from $2\frac{1}{2}$ to 4 feet apart, and over the entire area which the structure will occupy. When placed too close the driving in of one pile may have the effect of raising the others. They are driven, in the majority of cases, through the soft material and should penetrate a short distance into the hard stratum underneath.

93. A safe load on piles under these conditions may be taken at 1000 lbs. per square inch on the area of its head. In the case of a hard stratum not being attainable at a reasonable depth, the piles are then wholly supported in position by friction; a safe load of only 200 lbs. per square inch of area of head is permissible under such circumstances. The driving points of piles are armed with a cast iron shoe, fixed on by wrought iron straps, the weight

of these varying according to the dimensions of the pile. The head is protected by a wrought iron hoop, which prevents it being split by the blows from the ram of the piling machine. In order to ascertain when a pile has been sufficiently driven home, a test should be resorted to; that given by Professor Rankine is, "No further penetration should take place than one-fifth of an inch by thirty blows of a ram weighing 800 lbs. falling 5 feet at each blow."

The heads of each set of piles are sawn off level to the desired height to receive the platform, which consists of string and cross pieces 10 to 12 inches square, and half-notched into each other, laid directly on the pile heads and fixed by spikes. These wooden beams or cross and string pieces are surmounted by planks 3 to 4 inches thick, on which rests the lower foundation-course of the structure. Previous to fixing the planking, the soil, to a depth of from 3 to 6 feet below the level of the head of the piles, is excavated or scooped out, and the space up to the under side of planks filled in with concrete.

94. Iron and Screw Piles.—Hollow iron piles are sometimes used for a similar purpose, the blow of the ram being transmitted by using a block of wood or dolly on the head of the pile.

Screw piles are likewise used. These are sometimes made of wood, but are usually cast iron hollow cylinders, with a screw blade attached at the foot, having a diameter of from two to eight times that of the shaft of the pile, according to the nature of the soil to be penetrated. The method adopted in fixing the piles in their permanent position is that of turning them around, with the screw attached, by levers fastened to and radiating from a capstan fitted on to the shaft of the pile.

95. Coffer-dams.—The foundations of abutments and piers of a bridge crossing a river require in their construction additional protective works as compared with similar erections on land. Coffer-dams have been employed as a means of assisting in preparing the bed for foundations, and securing them from the action of water. They are generally constructed of guide piles 12 to 15 inches square, spaced at intervals of from 6 to 10 feet, and driven to the desired depth. Two longitudinal waling pieces, notched, are bolted to each side of the guide piles, the lower set being fixed as far down as the water level of the river will permit; the other set should be attached near the head of the piles. Between the guide piles and in the space formed by the waling pieces, sheet piles 3 to 6 inches thick are driven as close together as possible and to the desired depth. At a proper distance apart, generally from 4 to 6 feet, another line of guide and sheet piles are driven parallel to the first row, forming a long narrow trough, enclosing the site where the foundations are to be laid.

The soil between these rows of piles is removed, sometimes by dredging, until a hard compact stratum is reached. The whole space up to, in many

instances, a few feet above flood level is filled with clay puddle. When the coffer-dam is complete, the water it contains is pumped out and the ground excavated to the required depth when the foundation courses are commenced, or a thick bed of concrete is spread over the space between the piling.

A single row of guide and sheet piles is sometimes made use of as shown in fig. 37, the scantlings of the timber being heavier than those used for forming a double row. Great care must be exercised, in driving the sheet piles, in order to obtain an impervious coffer-dam, while it must be thoroughly braced internally to resist the pressure of the water surrounding it. These methods of obtaining a foundation, although much practised in

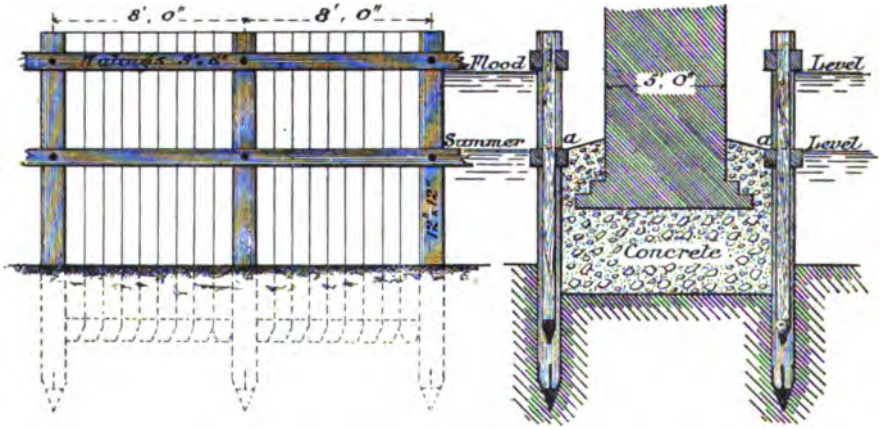


FIG. 37.—Section of coffer-dam showing single line of guide and sheet piles.

past years, and still adopted to a limited extent on small works, have been superseded by the system of caisson foundations.

The coffer-dams just described are costly to construct, and cause a considerable obstruction in a river or stream, while if, owing to the work not being carefully executed or to the external pressure of the water being great, they are not water-tight, constant pumping is necessary in order to keep the foundation-bed dry during the progress of that portion of the work.

95a. Cylinders and Caisson Foundations.—Cylinders or caissons are now extensively used, in building bridges of any magnitude across rivers, as a means of securing a stable foundation, for which purpose they are admirably adapted, and at the same time they are comparatively inexpensive. The superstructure of a bridge may be supported by two or more cylinders joined by arches or ties at a convenient level, on which the abutments or piers are built.

A cylinder, 6 feet or more in diameter, made of cast iron, or of steel

built in segments, bolted together, and having the joints made water or air tight, is the form generally adopted. The base, which is sometimes of a greater diameter than the cylinder, is formed with a tapering piece having a cutting edge. The interior of the cylinder is lined with one or more rings of brickwork, which will give it weight, and thereby add to the efficiency of the cutting edge in sinking. The material inside the caissons is removed by dredging, or by the use of mechanical excavators. When they have to be sunk to a great depth, the use of compressed air is invaluable in carrying on the operations. It is necessary to exercise great care in sinking cylinders,

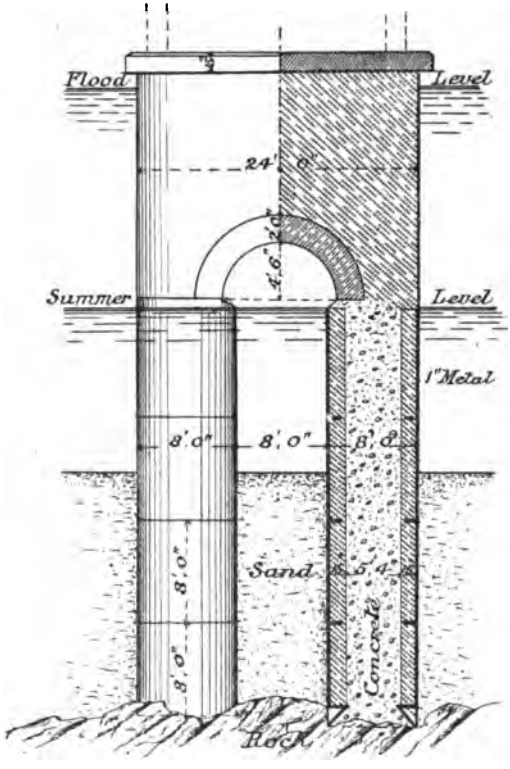


FIG. 38.—Cylinder foundations for piers.

so as to retain them in a vertical position, while their location in relation to the line of the bridge demands attention.

When the excavations have been made to the desired depth, the space inside the cylinders is filled up to a certain height, generally the normal water level, with concrete.

This method of forming foundations with cylinders is shown at fig. 38.

96. Abutments and Piers.—These generally consist of masonry, em-

bracing stone, brickwork, concrete, ironwork, and occasionally timber. It is advantageous in building abutments and piers to reduce the weight, if possible, by forming hollows or narrow archways in them so as to promote economy and stability. These openings must have inverted arches at the bottom to distribute the load over as great a base as possible, and may occupy one-third of the total volume of the wall.

97. Thickness of Abutments.—In practice, the thickness given to the abutments of bridges varies from one-third to one-fifth of the radius of the arch at the crown. In bridges the superstructure of which is formed with girders, the dimensions necessary for stability are regulated by their sufficiency to bear the vertical pressure transmitted by the superstructure.

98. Thickness of Piers.—Piers carrying arches of small span should be broad enough to accommodate the combined thickness of both arches and also allow of a space of at least 6 inches between them. In practice, the thickness generally given to the top of a pier sustaining large arches averages from one-sixth to one-tenth of the span; in viaducts, 'abutment piers' are introduced at each fifth or sixth pier, and generally have a thickness of one-fourth of the span. The object of building abutment piers is to limit the destructive effect of an accident to any of the intermediate sections.

High piers, in addition to the thickness allowed for according to the preceding rules, are generally built with a batter of 1 in 12.

99. Arches.—Arches may be constructed of cut stone, brickwork, concrete, iron, or timber. In form they may, for bridges of large span, be semicircular, elliptical, or a flat circular arc; the latter, with a rise of one-fourth of the span, is greatly made use of in practice, and is considered the simplest and strongest form of arch.

The stones composing the arch of a bridge up to 80 feet span are generally made of the same depth; beyond this span it is essential that the depth of the arch stones towards the abutments should be increased from one-fourth to one-half that of the keystone.

100. Depth of Arch Stones.—The following empirical expression in general use for the depth of the keystone is given by Professor Rankine—

$$D = C\sqrt{r}$$

when D equals the depth of the keystone, C is a constant and r the radius of the arch in feet at the crown. The value of C is as follows:—

TABLE IX.

For first-class stonework, ...	C = ·36
For second-class stonework, ...	C = ·4
For brick and rubble, ...	C = ·45

The joints of cut stones or ashlar forming an arch should have a moderate

degree of roughness to resist displacement by sliding, and also to aid the adhesion of the mortar.

It is essential that these joints should be properly dressed to template and fitted in position, to test their accuracy before they are finally laid in mortar. The arch stones should be properly bonded, that is, overlapped or break jointed; this has the effect of distributing the pressure and of tying the building together.

101. Brick Arches.—Brick arches may be built of gauged or of common shaped bricks. In practice the latter are generally employed, the arch being built in concentric rings half a brick thick. They are thus all laid as stretchers, a somewhat deficient form of construction; the upper joints should therefore, especially in arches having a considerable rise, be pinned with pieces of slate, and built with cement mortar as tenacious as the bricks themselves, to insure the several rings of bricks being properly connected.

Headers are sometimes introduced at intervals, which embrace one line more of stretchers in the second than in the first course, so that by this means the continuity of the concentric rings is broken.

Brickwork arches are usually built of the following dimensions:—

TABLE X.

Arches of 12 feet span are made				14½	inches thick.
,,	24	,,	,,	18	,,
,,	30	,,	,,	22½	,,
,,	40	,,	,,	27	,,

The backing of an arch may consist of coursed ashlar, rubble masonry, or concrete, built to a proper level. Provision should be made, in the event of water finding its way from the road surface, to protect the arch and backing by covering the exposed surface with asphalte, and collecting and discharging the water by suitable means through the arch at the lowest points to the surface of the ground.

102. Spandril Walls.—The walls built on the top of the arch rings up to the level of the roadway are called spandrils; these should be of sufficient strength to withstand the lateral pressure of the filling material and the traffic.

In many cases it is advantageous to introduce internal spandril walls built parallel to the external ones on the top of the arch, and covered with flat stones; or small transverse arches may be turned between the walls to support the material forming the bottoming of the highway, the spaces underneath being left hollow. When these internal spandril walls are high, they should be strengthened by building cross walls at intervals.

This method of construction is favourable to stability and lightness, and when adopted the external spandril walls become abutments to the transverse arches, and therefore must have sufficient stability to withstand the

thrust imposed upon them. The exterior spandril walls immediately above the keystone of the arch at each side are in most cases finished with a projecting string course, on which the parapets of the bridge are erected.

103. Forming Embankments over Bridges and Culverts.—In forming embanking over culverts and arches of bridges, near abutments, wing-walls, and retaining walls, care must be taken not to injure the masonry by unequally distributed or sudden pressures. As a precaution, dry earth should be spread in thin layers and rammed immediately behind and extended to a distance of about 8 feet from the masonry. It is also essential, when banking over large arched bridges and culverts, to carry it up simultaneously on either side to prevent unequal lateral pressures against the structure.

104. Centering.—Considerable attention must be given to the construction of the centres, an indispensable accessory, on which the arch stones are supported during erection. They are constructed of timber, and consist

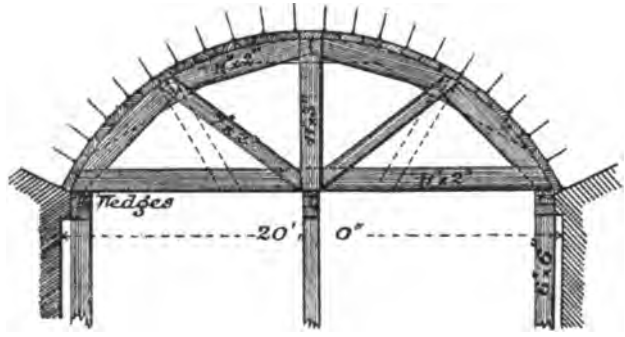


FIG. 39.—Showing scantlings and arrangement of centres for a bridge of 20 feet span.

of parallel frames or ribs, which should be made as rigid as possible. This rigidity is best attained by adopting one of the three following plans stated in Professor Rankine's *Civil Engineering*:—(1) Direct supports, (2) inclined struts in pairs, and (3) trussed wooden girders. For small arches the centres may consist of several light frames or ribs, made up in one or more thicknesses and bolted together. The upper edge is curved to suit the intrados of the arch, and on the top of these ribs planks are laid called *laggings*. Uprights with soles and sills are placed near the springing of the arch, and a similar arrangement is carried out at intermediate points between the abutments or piers where practicable. For light arches the ribs may be erected according to the size of the timber used for the framework, and the distance apart at which the ribs are placed.

Fig. 39 shows what would be suitable for an arch of 20 feet span and of brickwork 18 inches thick. The ribs may be spaced at from 3 to 5 feet apart, according to the weight of arch, the laggings being $1\frac{1}{2}$ inch

thick in the former case, and 2 inches in the latter. The struts are placed as shown in the figure, or they may be fixed at right angles to the arch, as shown by the dotted lines. The centering shown in fig. 39 has a support midway between those at the abutments. With a span of 15 feet similar scantlings of timber may be used, but without the centre support. Centres for large arches are constructed of heavy timber, and are sustained either on intermediate supports across the span, or, when this is not practicable, on the foundations of the abutments or piers at both sides. In the former case, with arches of considerable span, the curved parts of the ribs carrying the laggings are supported by struts sometimes placed perpendicularly to the intrados, resting upon horizontal beams fixed on upright timbers, or piles for river work, carried up from the ground level. These struts may also be placed in a vertical position and be strengthened by diagonal bracing to counteract any tendency to lateral flexure. With this form of centre the frame is not liable to change shape should the building of the arch stones be carried up to a greater extent on one side than on the other during construction.

In the other case mentioned, where an intermediate support for the centres cannot be fixed sufficiently near each other, a system of inclined struts in pairs or trussed wooden girders should be employed, but this is a complicated arrangement. Stiffness being essential, polygonal frames and timber arches should be avoided, owing to their flexibility.

105. Wedges and Striking Blocks for Bridge Centres.—It is necessary, when erecting a centre, that provision be made for its being easily removed when the arches are completed. The simplest method of accomplishing this, especially in centres of small bridges, is that of placing double wedges having a taper of 1 in 6 or 1 in 8, on the sills immediately under each rib or centre, as shown in fig. 40. For large spans wedge-shaped steps are employed called *striking plates*. It is of the utmost importance, especially in bridges of very long spans, that the centres should be lowered gradually in order to allow the arch to take equal settlement.

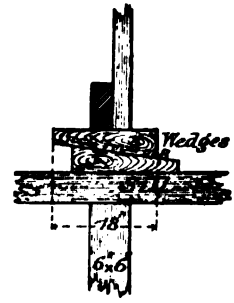


FIG. 40. — Details of lowering wedge for centres of small span.

The wedges should have a long taper of about 1 in 10, and be marked in a distinctive manner so that each rib may be lowered by an equal amount at the same time. The time and extent of easing and striking centres depend on the size and weight of the arch, temperature, composition of the mortar, and the class of masonry of which the arch is constructed. Centres may be eased immediately after the arch (built with lime or slow-setting cement mortar) is loaded to stability, while the centres should be struck in from five to eight days. The same remarks apply generally to small arches

built in cement, only the centres should be struck sooner; in large arches, however, built with quick-setting cement mortar, it is considered inadvisable to ease the centres at all. The cement in the portion of the work first built will have set before the completion of the arch, and any easing would injuriously affect the setting of the cement in the portion of the arch which was executed last. Disturbance of the work by vibration should be guarded against, as it destroys the setting power of all kinds of mortar, especially of cement. The centering for concrete arches should not be disturbed for at least fourteen days after finishing the concrete.

106. Centres for Arches of Bridge over the River Don and London Bridge.—The centering shown in fig. 41 is Telford's design for a centre with intermediate supports, used for a bridge over the river Don, of which the span is 75 feet, while fig. 42 shows the pier centering of trussed girders adopted in the building of London Bridge.

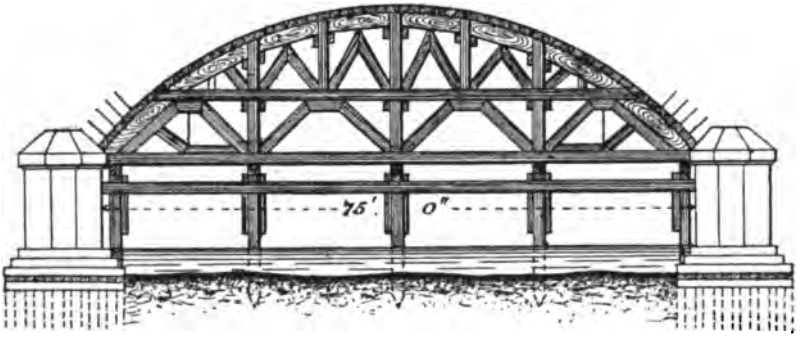


FIG. 41.—Centre for arch of a bridge over the river Don.

The latter illustration shows that one-fourth of the span at either side was directly supported by piles and diagonal bracing. The rib across the middle half of the span was formed of a diagonally braced girder of great stiffness, the depth being one-fourth of its span. The striking plates and wedges by which the centre is lowered after the completion of the arch, are shown in the figure, *a* being the upper plate, *b* the lower plate, and *c* the compound wedge, which is kept in position by the cross wedges *d*.

107. Iron pipes 1 foot long, filled with dry sand, and provided with a cylindrical block of wood fitting into the top, placed under the ribs of the centering, are sometimes used as a substitute for wooden wedges in easing and striking centres. The process of lowering is accomplished by allowing the sand to run out of the cylinders as required.

108. Timber Bridges. — Bridges erected with timber supports and superstructure are now an almost obsolete form of construction in this country, except for temporary purposes. Timber beams resting on abutments or piers of masonry are used to a limited extent when the span is

small and the traffic unimportant. In those countries where timber is abundant many large bridges have been erected with this class of material, and when properly protected and painted are said to last about twenty years. The simplest manner in which timber can be applied, when the

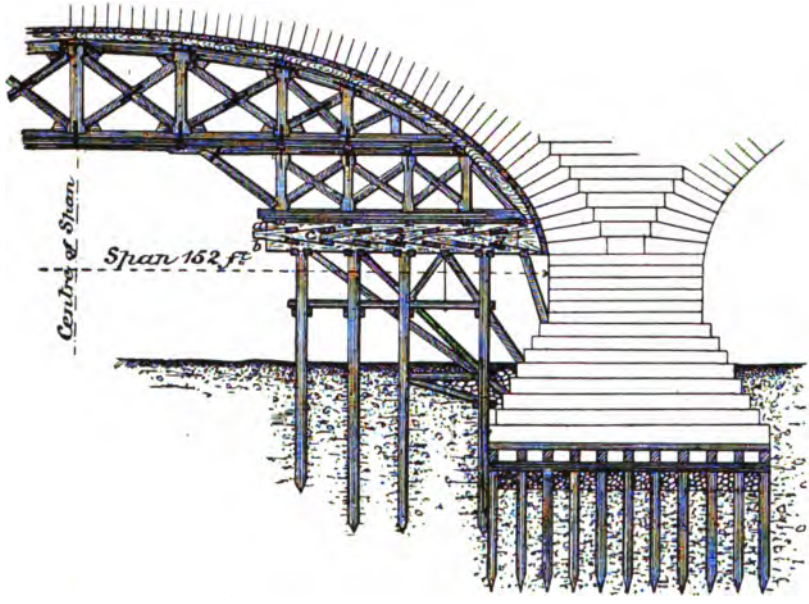


FIG. 42.—Centre for arch, London Bridge.

supports are of masonry, is in the form of beams or string pieces with cleading fixed on the top to carry the roadway. When the span exceeds

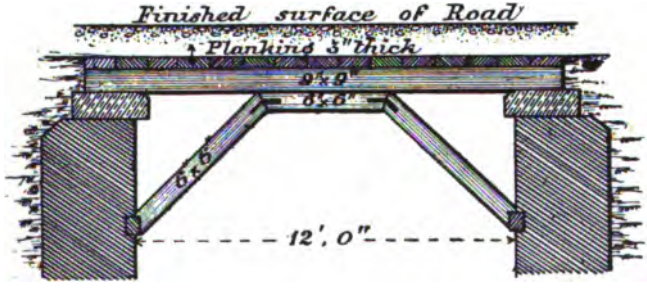


FIG. 43.—Timber bridge for small span.

8 or 9 feet, struts are generally introduced, as shown in fig. 43. Another form of construction suitable for spans up to 30 feet is shown in fig. 44, and may be used for bridges carrying light traffic. Beyond these spans different forms are employed, such as trussed girders composed principally

of struts and ties, with parallel top and bottom beams, or in the form of an arch.

Timber bridges, owing to their perishable nature when subjected to the influence of alternate wet and drought, should not be made use of except when other suitable materials are not available. The annual cost of repairs upon timber bridges becomes a heavy item, and in the course of a few years will equal, if not greatly exceed, the expenditure which the building of a permanent structure of stone or brick work would entail.

109. Iron and Steel Superstructures.—The superstructure of bridges formed with iron or steel has to a great extent superseded the ordinary masonry arch, in bridges of long span, or where the line of the bridge is at a considerable angle to the object crossed. The employment of cast iron is limited to bridges having short spans, the roadway being carried by jack arches built between and springing from the lower flanges of the beams; the arching being generally made 9 inches thick, and covered with a $\frac{3}{4}$-inch layer of asphalte or other impervious material. The space between the beams and over the arches is filled with concrete, broken bricks, or other material of a like nature, up to the level on which the metalling is spread.

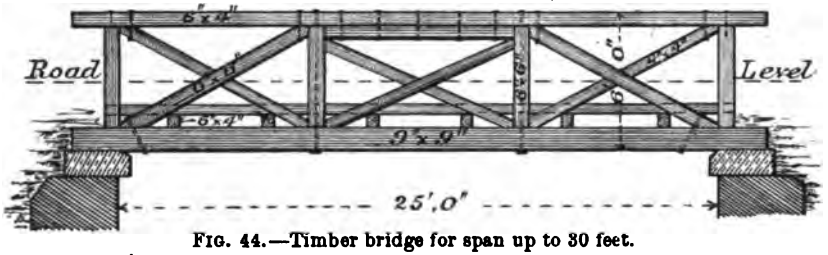


FIG. 44.—Timber bridge for span up to 30 feet.

The thrust on the outside or face-girders, when jack-arches are employed, is provided for by means of tie-rods $1\frac{1}{2}$ to 3 inches in diameter, placed at intervals across the bridge from 5 to 8 feet apart, which bind all the longitudinal girders together. This method of construction is illustrated in fig. 45.

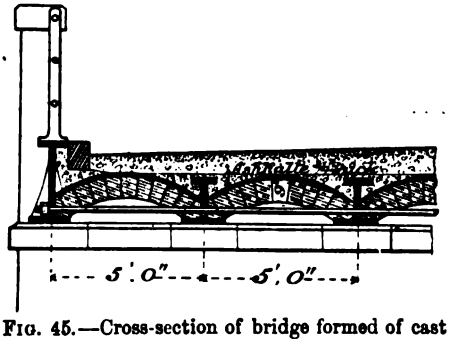


FIG. 45.—Cross-section of bridge formed of cast iron beams and jack-arching.

The superstructure of most bridges is now constructed of wrought iron or steel. The plate girder of uniform depth or hog-backed shape has been greatly used, and was the form employed almost exclusively previous to the lattice type being introduced.

The plate girder is still made use of in spans up to 60 or 70 feet; beyond this it is more economical to employ girders of the lattice type, which may have parallel booms, or be constructed on the bowstring principle; sometimes, however, they are built in the form of an arch.

When the head-room or height to the under side of the girders in crossing an existing line of communication, railway, canal, or navigable river is limited, only outside main girders are employed to carry the roadway. When, on the other hand, no such restriction is involved, the roadway may be carried on the top of a series of plate or lattice girders having a uniform depth. In the former case cross girders, of the plate or lattice type, are required, and extend between the main girders to the lower flanges of which they are fixed. These transoms or cross girders are built with a camber similar to that of the rise of the transverse section of the road; they are spaced from 6 to 10 feet apart, on which bearers running parallel to the main girders are fixed, and on the bearers convex buckle or corrugated iron plates are riveted, which, extending the whole width across the bridge, completes the superstructure. These plates are generally covered with asphalte, but concrete, composed of cork and bitumen, is also made use of on account of its lightness, while fine cement concrete is at times employed to protect from moisture the ironwork on which rest the materials composing the road.

110. Steel Trough Decking.—Steel trough decking is now extensively used in forming the floor or deck between the main girders of bridges, and may be fixed on the top or to the web and lower flanges of these girders. This form of decking is gradually superseding that of cross girders and buckle plates in the construction of the steel superstructure of bridges. Trough decking may also be used, not in the form of a cross girder but longitudinally, in which case the outside or main girders are dispensed with, and their employment insures a considerable saving on the first cost of constructing bridges up to a span of 36 feet. They are designed to carry with safety live or moving loads, comprising the weight of road-rollers and of traction-engines, in addition to the ordinary loads to which road bridges are subjected. The cross-section of a road bridge with this type of superstructure is illustrated in fig. 46. The dimensions shown are suitable for spans of from 16 to 20 feet; the weight of the steel decking for these spans is from 25 to 30 lbs. per square foot respectively.

111. The gradients of the approaches to many existing bridges and culverts could be greatly improved by substituting trough decking for the rubble arches of which many of these are built when they fall into a state of disrepair and require renewing. The relative cost of building an arch of brickwork in cement, including haunches, spandrils, and centering, for a bridge having a span of 20 feet, would be about 3s. 2d. per square foot of area covered; and for trough decking, assuming that the abutments are

built to the same height in either case, 2s. 8d. per square foot. The saving effected in the construction of the superstructure of such a bridge 16 feet wide would be £15 in favour of steel trough decking.

112. Protecting Dangerous Places.—All roads at dangerous points should be protected to prevent accidents to pedestrian and vehicular traffic. This, as a rule, applies more forcibly to precipitous hillside and mountain roads. Road authorities are under an obligation to perform the work necessary in carrying out these protective works, while the roadsides on level ground are fenced by the proprietors through whose land the highway passes. Many methods are in use for accomplishing this.

Earthen mounds are the most economically formed, but are generally in time raised too high by the roadside accumulations being heaped upon them, whereby free circulation of air on the road surface is prevented. The outlets or cuts for discharging the surface drainage of the road require

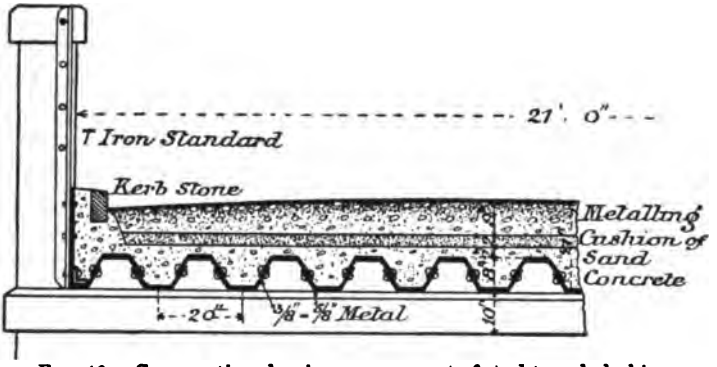


FIG. 46.—Cross-section showing arrangement of steel trough decking as applied to bridge work.

special attention where this form of protection is adopted. Parapet walls of stone built dry are an efficient and economical means of protecting a road, where such material is available. In sidelong cuttings, where retaining walls are a necessity, the parapet walls are formed by continuing these to a proper height. They should have a thickness of at least 18 inches, and be 3 feet 6 inches to 4 feet high, finished with a rough cope set on edge, while the outside joints and cope should be pinned and pointed with lime mortar. The most common fence, however, is that of the quick-set hedge, planted on the top of a raised mound made from the excavations in forming the ditches. It makes a good protection after the lapse of some time, but requires in the interval a considerable amount of attention. An open post and rail fence answers the purpose very well, while wooden and iron posts to which plain galvanized iron wires are attached is the method adopted in districts where building stones cannot be conveniently obtained. The great objection to stone fences is that, being liable to decay and damage,

they are expensive to maintain. So far as the durability of the road surface is concerned, this is best promoted by having open fences, as by this means of protection the beneficial influence of the sun and wind in producing evaporation is not lessened; while with close fences, such as stone walls and hedges, especially if they be high, the beneficial effects mentioned are diminished to a considerable extent.

113. In districts where snowstorms are prevalent during the winter months, the existence of close fences alongside a highway, apart from those for protecting dangerous places, is a source of considerable expenditure in opening the roads for traffic after a snowdrift. Where walls and hedges form the boundary line of a road it is not an uncommon experience to encounter a snow cutting of 6 feet in depth the full width of the roadway, and extending in many instances for miles, while the adjoining fields are comparatively free from snow.

In the author's experience, the cost of clearing snowdrifts has amounted, on many occasions, to from £400 to £600 over a district of between 200 and 300 miles, and this expenditure in all probability would have been saved, or at all events greatly reduced, had open fences existed instead of walls and hedges. Besides the heavy cost thus entailed, considerable damage is done to the road surface by the melting snow, especially where there is heavy vehicular traffic. It is doubtful, even on consideration of the preceding facts, whether any improvement may be looked for in the direction indicated. The protection afforded to farm stock when grazing, and the capital expenditure already involved in providing these close fences, remove to a remote date any probability of a change, or it might be said reform, being brought about.

CHAPTER IV.

ROAD MATERIALS OR METAL.

114. The bearing of the science of geology in relation to the formation of new roads brings the engineer into close practical contact with this subject, and on the manner in which the prominent physical features and underlying strata composing the earth's crust are examined will the ultimate success of the undertaking greatly depend. A knowledge of geology is also of great service in selecting a site for a quarry from which suitable rock may be obtained, either for the construction of a new road, or for preparing metalling for the maintenance of existing highways. The hard igneous, plutonic, and metamorphic rocks generally used for road work constitute large masses in the crust of the earth, which are now exposed at the surface, or form veins, dykes, and intruded sheets in the strata overlying them.

115. A sufficient knowledge of the locality and general geological structure of the particular stratum desired may be readily obtained, in the first instance, by a study of the coloured maps, with sections of the strata of which the surface of the country is composed, issued by the Geological Survey of Great Britain.

116. Rock Materials for Roads.—The different varieties of rock from which macadam is prepared for the construction and maintenance of roads, and the making of setts for paved streets, vary to a considerable extent in their component parts, and also the degree of crystallization which has taken place. It is very seldom, indeed, that two samples of rock taken from adjoining quarries, at no great distance apart, are found to contain the same proportion of 'simple minerals,' while in cases of rock taken from the same quarry the primary forms of crystallization are quite distinct, forming different varieties of structure, although the chemical composition may be similar in each case.

The igneous and siliceous rocks form the greater bulk of the materials used in road making and repairs, but many other different kinds of stone have been, and still are, used for this purpose.

Granite and syenite are the principal rocks of which setts are made for paving carriageways, or streets in large towns, where vehicular traffic is heavy and continuous. The trap rocks, greenstone or whinstone, and basalts are also greatly used for this purpose, but their durability, unless in isolated instances, cannot be compared with that of certain granites and syenites.

117. The Mineralogical Composition of different Rock Materials for Roads.—The materials employed for road metal are prepared from different kinds of rock, the principal of which are Granites, Syenites, Diorites, Basalts, Dolerites, Diabases, Quartzites, Mica-schists, Limestones, Ragstones, Sandstones, Flints, and Gravel taken from pits, river beds, or the sea-beach.

The mineralogical composition of rocks varies considerably, while a great difference exists in the chemical stability of many of the minerals composing them. The mineralogical peculiarities or qualities combined in a typical road stone depend principally on the composition, and to a great extent on the manner in which the different minerals are aggregated together, such as the crystalline texture and the nature of the base or matrix, forming a kind of paste or cement in which the crystals are imbedded.

The conditions under which rock masses have been hardened can be tolerably well ascertained by noting the degree of crystallization which they have undergone. This depends to a considerable extent upon the slowness or rapidity with which they have cooled, and the depth at which consolidation has taken place. Generally speaking, each mineral has its own temperature point at which it crystallizes. When rock has chilled rapidly it appears glassy, the crystals not having had time to form; while, on the other hand, if the cooling process of the molten mass has been extremely slow, the chemical elements have had time to assort and arrange themselves into chemical compounds, and in obeying the laws of crystallization to assume special forms.

118. Granite.*—Granite is composed essentially of felspar, mica, and quartz aggregated together in a thoroughly crystalline-granular manner. The felspar is either orthoclase (potash felspar), albite (soda felspar), or oligoclase (soda-lime felspar), the former generally prevailing, the latter being found in smaller quantities.

The predominant mica in granites is the muscovite (potash) variety; the dark brown or black variety biotite (magnesian mica) is also found, while lepidomelane or haughtonite is of rare occurrence. The quartz or pure silica sometimes forms a paste in which the other minerals are embedded, and occasionally the component ingredients are found as independent crystals. The other accessory minerals, beryl, topaz, and tourmaline, are found in cavities of the granite when the minerals occur as independent well-formed crystals.

* The description of some of the rocks mentioned in the immediately following paragraphs is partly taken from the article on 'Geology' in the *Encyclopædia Britannica* by Professor Geikie.

The texture of granites varies considerably, from coarse crystalline masses to fine granular rocks, which pass into elvanite or felsite, and form an intermediate stage between granite and quartz-porphyry.

Of the different kinds of granite, those which are compact and fine-grained, and composed of orthoclase and muscovite, may be taken as a reliable material for road metal. The quartz and mica are practically unaltered chemically; the felspar, however, especially when oligoclase is present, decomposes rapidly into clayey mud on being subjected to the disintegrating influence of air and water. Granites vary in colour from a grey hue when the crystals of felspar are dusky white, to red when they are coloured by the presence of iron.

Quartz-Porphyry.—Certain rocks, closely allied to, and sometimes called granites, are Quartz-porphyry, Felsite-porphyry, Felstone, and Felsite. These are composed of a mixture of orthoclase and quartz as the essential constituents, little or no mica being found in their composition. When the quartz forms conspicuous crystals the rock is called quartz-porphyry, but when the felspar and quartz are intimately mixed so as to present a homogeneous matrix the rock is termed felsite-porphyry, felstone, or felsite; they are generally very compact in texture or even flinty in appearance. Triclinic felspars occasionally occur in these rocks, while the minerals mica and hornblende accompany the essential constituents; apatite, magnetite, and pyrite being at times met with as accessories. The colours of these rocks vary from flesh-red, purple, yellow, to slate-grey, depending chiefly on the felspar, while dark-grey, brown, and greenish tints are imparted by the presence of mica or hornblende.

119. *Syenite.*—This name is now restricted to rock consisting essentially of a mixture of orthoclase and hornblende, but which was formerly applied to granite when the mica was replaced by that of hornblende. In addition to the component elements mentioned, the minerals plagioclase, quartz, and mica are occasionally added as accessories. The durability of syenite is greater when quartz and hornblende predominate; felspar and mica are weak and of a perishable nature if present to any great extent, and disintegrate rapidly, especially when the crystals are large and have a dull appearance. The colour of syenite varies from pink to grey. In most cases the rock forms an excellent stone for road-metalling purposes.

120. *Syenite-porphyry* contains little or no quartz, but has a little plagioclase, and sometimes hornblende and biotite or black mica; it is an orthoclase rock, and is usually termed orthoclase-porphyry. Syenite-porphyry is closely allied to syenite, being associated with that rock much in the same way that elvanite is with granite.

121. *Diorite.*—Diorite is the term applied to greenstones or whinstones, and consists of a crystalline mixture of oligoclase or some allied felspar and hornblende, with magnetic iron and apatite. These rocks occur in an

eruptive form, and under conditions similar to syenite; the more dark compact varieties are sometimes called *aphanite*, while those containing free quartz are known by the name of *quartz-diorite*. These rocks form a large proportion of the material used for road repairs in Scotland, and when the component minerals are fine-grained and compact they make very durable and satisfactory road metal. On the other hand, those which contain soda and lime felspar, combined with a coarse texture, quickly decompose and form clay, which creates on the roads during wet weather large quantities of mud. *Hornblende andesite* is a rock similar to diorite, the felspar being plagioclase; when it contains free quartz it is called *dacite*.

122. *Basalt.*—This rock consists of a triclinic felspar, generally labradorite, together with augite, olivine, and magnetic or titaniferous iron, with apatite and sometimes sanidine or nepheline. The augite in basalt plays a similar part to that taken by hornblende in the rocks just described; it is also a mineral constituent of most of the following series. Basalt is a volcanic rock of great importance, and occurs as dykes, veins, intrusive bosses and sheets, while sometimes it presents a columnar structure. It is close-grained and compact, the dark colour being chiefly due to the large proportion of magnetite, which also contributes to its high specific gravity. The term *dolerite* is given to the more coarsely crystalline varieties of basalt, the durability of which is very variable.

123. *Diabase* is a name given to rocks consisting essentially of the same mineral constituents as basalt; they are, however, much older, and having been longer exposed to metamorphic processes are consequently less fresh than basalts. Most varieties of basalt are eminently suitable as material for macadam; they are generally durable and hard, combined with the other qualities upon which depends the value of road metalling.

All the rocks described are of igneous origin, their internal characteristics being either purely crystalline, consisting entirely of crystals interlaced with each other as in granite, or half-crystalline composed of a non-crystalline amorphous matrix with crystals scattered through it; the latter division embraces most of the eruptive masses.

124. Among metamorphic rocks the quartzites and greywackes are best; many of these have a sufficient admixture of felspar, which tempers the natural brittleness of the quartz

125. *Mica Schist* is found in mountainous regions, and is much used as a road material in the Highlands of Scotland and in some parts of Wales. It is composed essentially of quartz and mica, disposed in layers which give it a stratified appearance. On this account it is not a suitable stone for repairing roads which have heavy traffic passing over them. This description of stone binds well, however, and makes a very good surface on roads with light traffic, but creates much mud in wet weather, while at the same time it has the advantage of drying quickly after a fall of rain.

126. The Carboniferous or Mountain *limestones* are greatly used in some counties in England, Wales, and Ireland for macadamizing purposes; they are very suitable for roads with light traffic, and make a good surface, but create large quantities of mud in wet and dust in dry weather. It can only be applied economically on the class of roads mentioned, and where the climate is equable; it is, however, rendered practically useless as a metalling material by alternate frost and thaw.

Ragstone or *Kentish-rag* is a limestone occurring with alternate layers of sandstone known as *hassock*, and belongs to the Lower Greensand formation. It is greatly used in Kent as a road material and for kerbs and channels.

127. *Sandstones* are greatly used, especially the harder kinds, for bottoming roads, but as a rule are too soft for metalling purposes; they also absorb a considerable amount of water. Many sandstones are chemically indestructible, but being loosely aggregated together are, under the wear of wheel traffic, quickly pulverized, the dust having little or no binding qualities. The millstone-grits are the best of this class, and may be used for surface repairs on roads with moderate traffic; they are, however, liable to rapid disintegration during drought and frost.

128. *Flints* are extensively used in the chalk districts of England; they give excellent results so far as a good surface is concerned, but are too brittle for heavy traffic. Those gathered from the surface of the land are superior to those dug from gravel-pits, or, as they are termed, quarry flints. The binding properties of flints are small, for which reason an admixture of ragstone or hard chalk is sometimes employed to produce a better road surface.

129. *Gravel* and *stones* gathered from the surface of the land are extensively used in districts where more suitable materials are difficult to obtain. The gravel, whether taken from pits, river beds, or the sea-beach, is all more or less rounded and worn. Stones of this kind, when used as metalling, make a very rough surface, and being of unequal hardness they wear very irregularly. Land-stones are not, for similar reasons, a suitable material for repairs, and their use should only be tolerated when a more suitable kind of stone is not available. Ironstone and copper slag are at times employed, especially for bottoming roads; as a metalling material they possess no binding properties.

Among stones of the same kind that which has the greatest specific gravity is invariably the strongest, but great difference may exist in the durability of stones of the same kind and presenting little difference in appearance.

Table XI. gives the chemical analyses of the more important rocks described in the preceding paragraphs.

130. The Requisites in a Road Stone.—In selecting a material for

TABLE XI.

*Chemical Analyses showing Composition of different Rocks.**

Name of Rock.	Silica.	Alumina.	Oxides of Iron.	Magnesia.	Lime.	Soda.	Potash.	Water.	Loss by Ignition.		Specific Gravity.
Granite, . .	72·07	14·81	2·22	0·33	1·63	2·79	5·11	...	1·09	100·05	2·66
Quartz-porphyry, .	76·92	12·89	1·15	0·98	...	0·68	4·27	1·97	...	99·54	2·49
Syenite, . . .	59·83	16·85	7·01	2·61	4·43	2·44	6·57	1·29	...	101·03	2·75 to 2·90
Diorite (Greenstone), . .	53·20	16·00	14·00 and manganese.	6·00	6·30	2·20	1·30	...	1·00	100·00	2·95
Augite-Andesite, .	67·35	15·72	1·94	1·16	3·60	5·04	1·86	...	0·36	101·06	2·75
Basalt, . . .	45·00	15·00	15·00 and manganese.	6·50	10·50	3·50	1·50	...	3·00	100·00	2·95
Gabbro (Diallage-Rock), . .	50·00	15·00	12·50 and manganese.	7·00	10·00	2·50	0·5	...	2·5	100·00	2·95
Trachyte, . .	60·00	17·00	8·00	1·00	3·50	4·00	5·00	...	1·5	100·00	2·65
Phonolite (Clinkstone), . .	57·70	20·60	3·50 and manganese.	0·50	1·50	7·00	6·00	...	3·2	100·00	2·58

* Abstracted from Article on 'Geology' in *Encyclopædia Britannica* by Professor Geikie.

the purpose of road making, the essential characteristics requisite may be summarized as follows:—

(1) *Hardness*, or "that disposition of a solid which renders it difficult to displace its parts among themselves."

(2) *Toughness*, or "that quality by which it will endure light but rapid blows without breaking."

(3) *Weather resistance*, or "non-liability to be affected by the weather."

(4) *Binding* properties.

The latter quality is of no value in stones for paved streets, and where steam-rolling is practised it is not of so much moment as when the metalling is consolidated by wheel traffic.

These qualifications are by no means always found together, and the selection of a suitable stone for road metalling under any circumstances is a somewhat difficult problem. Apart from the practical experience which one may possess of judging the quality of any particular rock, more particularly when opening a new quarry, the only rational and satisfactory means of determining the point is to make an experimental trial upon a section of roadway for a sufficient length of time, and over which a known amount of traffic passes. The results thus obtained can be compared with those shown on any other section of road similarly situated, and which has been maintained for years with a material of recognised quality.

This process takes time, however, which is a serious drawback when the exigencies of the case demand that material from a new source has to be found and tested within a reasonable period of time. In the maintenance of roads it should be the constant endeavour of those having charge of such matters to carry out the testing of material by actual wear in the road and the relative cost of such stone as is admittedly fit for the purpose. This should be done years in advance of any possible necessity for a change, by reason of the supply of rock in an existing quarry giving out, or the quality of the material becoming inferior.

131. Physical Tests.—When an actual trial of the material cannot be accomplished, recourse must be had to observation and previous experience in such matters, while physical tests are frequently made use of to attain the object in view, which are of great assistance generally. The results obtained have, however, only a relative value, and in many instances the conclusions arrived at are extremely delusive.

Of the many physical tests employed for this purpose the following may be mentioned:—

(1) The abrasion or attrition test; (2) the drop test; (3) the absorption test; (4) the weathering test; (5) the crushing test.

132. *The Abrasion Test.*—This is carried out by placing samples of broken stone in a revolving cylinder, sometimes along with a number of small castings.

The stones are weighed previous to and after testing, the loss in the form of dust and small chippings being thus ascertained. The machinery erected by the Hornsey District Council is a very complete plant for carrying out this form of test, a brief description of which is here given, as are also extracts from a number of valuable tests carried out by Mr. E. J. Lovegrove, A.M.I.C.E., engineer and surveyor to the Council.*

The machine used at Hornsey for testing the samples of road metal consists of three cylinders, each 11½ inches in internal diameter, and having three 1 inch by 1 inch angle iron ribs riveted lengthwise on the inside; it is driven by a gas engine.

The samples of stone to be tested are operated on by what is known as the dry and the wet process.

The same weight of stones is employed in each instance, namely, 4 lbs., these being placed in the cylinders and subjected to 8000 revolutions at a speed of twenty revolutions per minute. In the wet test the stones are weighed dry, and then placed in the cylinders, one half-gallon of water being added; the weight of the stones after testing being ascertained when they are thoroughly dry, and the loss recorded, from which the percentage in each case is calculated. The chips referred to in the tabulated statement vary in size, the dust being in the form of a fine powder.

It will be observed that Penmaenmawr granite (quartz-diabase), test No. 12, only loses in weight by the dry test 2·44 per cent. in the form of dust, while under the wet test there is a combined loss in chips and dust of 3·90 per cent. Quenast granite, a limestone resembling granite in appearance, loses in the wet test 4·54. Clee Hill Dhu stone, a basalt (dolerite), and recognized as an excellent road material, loses in the wet test in dust only 10·15 per cent., and Guernsey granite (hornblendic), also an excellent material for macadam, loses 14·06 per cent. by the wet test.

It is evident from the foregoing tests that if the samples of the different kinds of road metal treated are not similar as to size and cleavage or cubical shape, and in every other possible way, the results will vary accordingly, and that the harder the stone, and the less tough it is, the greater will be the amount of chips produced. A stone having a high specific gravity is also likely to leave a large quantity of chips.

In order to follow this method of testing materials for road purposes, and make a comparison of the results obtained with that of actual experience, on the different kinds of metalling used under varying conditions of traffic and weather, the following particulars may be given. Experiments by the abrasion test were carried out by Mr. E. J. Lovegrove for the author on samples of stone which were considered to be extreme in the separate properties of hardness and toughness, but not combined to any great extent. The results are shown in Table XIII.

* *The Surveyor and Municipal and County Engineer*, 5th November 1897.

TABLE XII.

No. of Test.	Description of Stone. (H.) Hand Broken. (M.) Machine Broken.	Dry Test.				Wet Test.				Specific Gravity.
		Weight of 4 lbs. of Stone after Testing.	Difference in Weight per cent.			Weight of 4 lbs. of Stone after Testing.	Difference in Weight per cent.			
		lbs. oz. drm.	Chips.	Dust.	Total.	lbs. oz. drm.	Chips.	Dust.	Total.	
12	Granite, Penmaenmawr, N. Wales (H.), . . .	3 14 7	·00	2·44	2·44	3 13 8	·14	3·76	3·90	2·73
24	Granite, Quenast (Limestone), Belgium (M.), . . .	3 14 2	·00	2·93	2·93	3 13 1½	·00	4·54	4·54	2·76
9	Granite, Enderby, Leicester (H.), ...	3 13 5½	·05	4·10	4·15	3 12 8	·00	5·47	5·47	2·64
2	Flints, surface, Strood, Kent, from, (H.), . . .	3 10 0	1·17	8·20	9·37	3 10 1½	1·95	7·27	9·22	2·71
	Flints, surface, Strood, Kent, to, (H.), ...	3 6 8	4·30	10·55	14·85	3 2 7½	6·25	14·89	21·14	2·63
14	Basalt, Clee Hill Dhu, Salop (H.), ...	3 12 2	0·00	6·05	6·05	3 9 8	·00	10·15	10·15	2·88
3	Whinstone, from near Lake Windermere, . . .	3 11 15	·15	6·20	6·35	3 7 7	·00	13·38	13·38	2·74
2	Flints, pit, Strood, Kent, from, (H.), . . .	3 8 11½	2·34	9·03	11·37	3 7 8½	5·86	7·37	13·23	2·63
	Flints, pit, Strood, Kent, to, (H.), ...	2 15 4	15·57	10·60	26·17	3 5 14½	5·12	10·64	15·76	2·69
24, 25	Granite, Guernsey, mean, (H.)	3 10 8¼	·00	8·57	8·57	3 7 0	1·22	12·84	14·06	2·97
23	Limestone, Mountain, Somerset (M.), ...	3 9 8	1·22	8·94	10·16	3 6 2	2·10	13·33	15·43	2·84
21	Kentish Rag (Limestone), Kent (H.), . . .	3 5 0½	·83	16·31	17·14	2 14 7	·00	27·44	27·44	2·66
	Blue Pennant Stone (sandstone), Pontypridd, . .	3 6 12	·00	14·45	14·45	2 14 6	·00	27·54	27·54	2·68

TABLE XIII.

Tabulated Statement of Tests.

No. of Test.	Description of Stone. (H.) Hand broken. (M.) Machine broken.	Dry Test.				Wet Test.				Specific Gravity.
		Weight of 4 lbs. of Stone after Testing.	Difference in Weight per cent.			Weight of 4 lbs. of Stone after Testing.	Difference in Weight per cent.			
		lbs. oz. drm.	Chips.	Dust.	Total.	lbs. oz. drm.	Chips.	Dust.	Total.	
1	Whinstone, Foodie Quarry, Fifeshire (H.), .	3 7 8½	3·66	9·58	13·24	3 0 0½	3·17	21·78	24·95	2·73
2	,, ,, ,, (M.), .	3 7 14½	2·50	10·15	12·65	2 15 3	2·54	22·75	25·29	2·73
3	Basalt, Newbigging Quarry, ,, (H.), .	3 7 7	3·32	10·05	13·37	3 3 5	0·19	19·63	19·82	2·97
4	,, ,, ,, (M.), .	3 8 5½	·00	11·96	11·96	3 2 5	·00	21·38	21·38	3·01
5	Whinstone, Mount Quarry, ,, (H.), .	3 9 0½	2·44	8·44	10·88	3 7 1	0·97	12·99	13·96	2·67
6	,, (red), Lindifferon Quarry, Fifeshire (H.), ...	3 9 6	5·12	5·22	10·34	3 12 2½	0·78	5·22	6·00	2·47
7	Basalt, Newbigging Quarry, Fifeshire (H.), .	Second test (wet only).				3 2 15	0·44	19·97	20·41	2·97
8	Whinstone (red), Lindifferon Quarry, Fifeshire (H.), ...					3 12 13	0·09	4·88	4·97	2·47

It will be observed that a second test was carried out in the case of Nos. 3 and 6; in the first test of these samples, 18 and 20 stones respectively made up the 4 lbs. necessary for the experiment, while 20 and 30 stones respectively were required to make up the required weight in the second test. The Lindifferon stone shows the best results for toughness by the physical test of abrasion, the wet test in the second trial showing a loss of only 4·97 per cent., while that of Newbigging similarly tested shows 20·41 per cent. of loss.

It is notable that in the case of the former stone the results obtained by the wet test are superior to those by the dry test by an amount equal to 5·37 per cent. This is a peculiarity, but the tabulated results obtained from the different tests of the stone are amply borne out in practice. It is an excellent material for surface repairs where the roadway is shaded or located in a damp situation. When steam-rolled it is very durable, and the detritus which is formed through wear is composed of fine sand; it is of a homogeneous nature, the grains being scarcely distinguishable. This material was only used to a limited extent previous to the introduction of steam-rolling, as, when laid in patches and exposed to the wheels of passing vehicles, the metalling was pulverized in dry weather, and as much so during frost. The test of experience shows that this stone is of a brittle or hard nature when in a dry state, while toughness appears to be stimulated by moisture. The Newbigging stone, an extremely tough basalt, does not come out well in the wet test compared with the Lindifferon stone just mentioned. It is nevertheless a very durable class of macadam, and its fitness, under all conditions of traffic and weather, as a suitable and economical material for road maintenance, has been recognized for a long period of years. These two specimens of stone will be further dealt with under the chapters on Quarrying and Stone-breaking.

133. *The Drop Test.*—This is carried out by subjecting the specimen of stone under examination to repeated blows from a falling weight. A machine for testing the tenacity of stones by this means has been used for a number of years by the Surveyor of the Truro Rural District Council, Cornwall. The hardness of a specimen of stone is found by the usual mineralogical test. The tenacity of the stone by this method of testing depends on the resistance of the material to a hammer weighing 15 lbs. falling 10 inches on the specimen, which is placed on an anvil. Samples of rock to be tested weigh 3 lbs., broken to road metal capable of passing through, in all dimensions, a 2½-inch ring. The macadam thus prepared is, by the repeated action of the weight falling, reduced sufficiently small for its passing through a sieve having a ¼-inch mesh, which size is taken to represent exhausted road metal, and the number of blows necessary to accomplish this being automatically registered. A sample of greenstone from Penzance,* No. 5 test, having a hardness

* *Vide* Paper read by Mr Thomas Clark, surveyor, Truro District Council, at the

according to the mineralogical test of 6·5, took 900 blows to reduce it. This represents in the drop test the tenacity of the stone, and the dust resulting from the experiment, under $\frac{1}{16}$ of an inch, is given as 12½ ounces. A sample of stone from Clee Hill (basalt), which has the same degree of hardness as the previous stone, shows a tenacity of 724, with 12 ounces of dust less than $\frac{1}{16}$ inch. It is considered by this test that any sample of stone which is unable to withstand 200 blows is unfit for road-metalling purposes.

The County Surveyor of Cornwall, Mr. T. J. Hicks,* commenting on the drop test as carried out and described in the preceding paragraphs, states: "Some years ago the surveyor of a highway district here introduced the only stone-testing machine I have yet seen that is worth anything, and even that is not entirely to be depended on. Taking spar under this test and greenstone spar, our worst material, gives hardness, 7; specific gravity, 2·56; number of blows, 264 to crush to dust. Greenstone, our best material, gives hardness, 6·5; specific gravity, 3·07; blows, 799; dust, 11 ounces."

"To show that this test is not altogether to be depended on, however, I know a stone that shows very little difference to the greenstone, and that costs about one-third more for breaking, yet under traffic it cracks up readily into gravel, and makes mud quickly."

134. *The Absorption Test.*—The absorption test consists in determining the liability of a stone to absorb water. It is carried out by weighing the stone carefully after being thoroughly dried, and immersing the sample in water for twenty-four hours. It is then wiped dry and weighed, the difference between the two results obtained being due to the water absorbed by the stone. The stones of admitted suitability for road-metalling purposes absorb, as a general rule, the least quantity of water.

Granite absorbs water to the extent of one part of the latter to every 80 to 700 parts of the former; it is notable, however, to observe that clay slate absorbs water in similar proportions to granite, as will be seen from Table XIV., taken from Prof. Rankine's *Civil Engineering*.

TABLE XIV.

Showing Proportion of the Absorption of Water by Different Stones.

Granite absorbs one part of water in from			80 to 700	parts of stone.
Gneiss	,,	,,	about 40	,,
Clay Slate	,,	,,	80 to 700	,,
Sandstone (strong, Yorkshire)		,,	30 to 60	,,

Clay slate has, of course, no place as a material in connection with road construction and repairs.

'Surveyor' Exhibit of the Building Trades Exhibition held in London, *Surveyor and Municipal and County Engineer*, 26th March 1897.

* Vide the *Quarry*, January 1897.

135. *The Weathering Test.*—This test is effected in a similar manner to the preceding, and has for its object the determination of the ability of the stone, after absorbing water, to withstand the effects of the disintegrating action of frost. It may be carried out artificially by soaking the stone in sulphate of soda (Glauber's salt) and hanging the sample up for a few days to dry. This process must be repeatedly performed, when it is said that the stone will behave as if under the action of a thaw succeeding frost. To properly carry out this test, however, it is necessary to expose the specimen of rock to the actual disintegrating action of frost. As in the absorption test, the stone is immersed in water for twenty-four hours, and then placed outside when the thermometer registers 32° Fahr. or under. The frozen specimen is then thawed and the process alternately repeated, when the loss in weight by disintegration is ascertained. As this test can only be effected during the prevalence of frost, it is consequently not always easy of application.

136. *The Crushing Test.*—This test consists in determining by means of a hydraulic press the resistance of a sample of carefully dressed cubes of stone to crushing. The results obtained by this physical test are, so to speak, of a positive nature; yet they may be very misleading in so far as the selection of a suitable stone for road metal is concerned. Too much importance is generally attached to this property, especially by quarry-owners.

To show how delusive it is to attach undue weight to a high resistance to crushing, solely on account of a stone possessing this property, the following different kinds of stone may be compared. A specimen of rock from the Clee Hill quarries already mentioned, which is described as a tough, hard, fine-grained basalt, and "almost perfect as a road stone," is capable of sustaining a crushing test of 6 tons per square inch. Guernsey granite (syenite), also an excellent stone, and much used in London and the southern towns of England for road repairs, shows a crushing resistance of 12·75 tons per square inch.

Flints, on the other hand, are a very suitable material where the traffic is moderate, and are used to a considerable extent in many English counties where more suitable material cannot be obtained. This description of material, however, cannot be compared with either of the preceding stones for durability when subjected to the vagaries of traffic and weather; nevertheless, it has a high resistance to crushing, being slightly over 14 tons to the square inch. From this comparison it is evident that a high resistance is no indication of the wearing qualities of a road stone under the practical test of traffic.

A stone having a high resistance to crushing clearly shows that other qualities are necessary in order that it may be successfully used for metalling purposes. It has been shown that toughness alone is not enough for a good stone to possess, while one having a high resistance to crushing is equally deficient; so that of these two properties, it is apparent that the one is quite

as essential as the other for a stone to possess in order that it may be considered as having good wearing qualities.

137. In France the Administration des Ponts et Chaussées has adopted a comparative numerical value of the quality of the materials used on the national roads. This scale of quality, ranging from 0 to 20, has been formulated from the combined results of experiments, attrition and crushing tests; and the quantity of materials consumed by a certain amount of traffic. The following is a list of most of the varieties of rock used, with the quality of each kind expressed numerically:—

TABLE XV.

(*Ministère des Travaux Publics Routes Nationales*, 1893.)*

Porphyry,	varying	from	10 to 20
Trap,	,,	,,	16 ,, 20
Basalt,	,,	,,	10 ,, 19
Quartzite,	,,	,,	11 ,, 19
Grès Quartzose,	,,	,,	10 ,, 20
Flint,	,,	,,	8 ,, 19
Quartz,	,,	,,	10 ,, 18
Serpentine,	,,	,,	12 ,, 18
Melaphyr,	,,	,,	16 ,, 17
Diorite,	,,	,,	13 ,, 17
Limestone,	,,	,,	5 ,, 17
Gneiss,	,,	,,	5 ,, 17
Granite,	,,	,,	8 ,, 16
Millstone grit,	,,	,,	6 ,, 16
Amphibolite,	,,	,,	11 ,, 15
Schist,	,,	,,	3 ,, 15
Mica Schist,	,,	,,	6 ,, 13
Puddingstone,	,,	,,	4 ,, 8

138. As bearing upon this subject of physical tests with special reference to the mud-producing proclivities of limestone, the results of the following interesting experiments may be given of road-stone testing carried out by Professor Elliot, University College, Cardiff,† on behalf of the *Western Mail* of that borough.

It appears from statements in this journal that most of the streets in that borough are of macadam, the material being generally limestone, basalt and granite being only used in special cases. As a consequence, it is asserted that no less than 30,000 tons of mud were removed last year from the Cardiff streets. With a view to remedying this state of affairs the *Western Mail* commissioned Professor Elliot to make tests of the various stones employed as macadam, the experiments being specially directed to ascertain-

* *Roads and Pavements in France*, by Alfred P. Rockwell.

† *Engineering*, 30th September 1898.

ing the respective mud-producing capacities of the different materials. To this end an 'attrition' apparatus was devised somewhat similar to machines previously used for the same purpose in France and America.

This machine was essentially a 'tumbler' of special design in which the stone to be tested was placed, together with a number of small cast iron blocks. This done, the barrel and its contents were rotated at a speed of 15 turns per minute for a total of 3600 revolutions. At the end of the experiment the loss of weight by attrition was ascertained by weighing; this formed a measure of the comparative mud-producing proclivities of the specimen. As was to be anticipated, the basalts and granites showed much less loss of weight than the limestones, as indicated in Table XVI.

TABLE XVI.

Material.	Dust or dry mud produced in 4 hours' Test, per cent.	Average compressive strength, tons per sq. in.
Basalt C,	5·8	12·45
Basalt A,	5·9	9·35
Basalt B,	6·5	12·02
Clee Hill 'granite,'	7·0	5·49
Penlee stone (basalt),	7·2	5·54
Clee Hill Dhu stone (basalt),	7·9	9·45
Wicklow granite,	8·0	6·41
Guernsey granite,	9·3	7·99
Aberdeen granite,	15·7	...
Red brick (hard),	16·9	...
Black limestone, Mumbles,	20·0	5·96
Cornish granite,	22·1	...
Road metal from Cardiff gaol store (Castell Coch),	22·5	...
Road metal from Cardiff gaol store (Ely),	24·6	...
Sweldon stone,	30·2	3·99
Cwymnofydd, Tongwynlais,	34·7	3·09
Hard sandstone,	89·4	...
Neat Portland cement,	89·5	...

139. It will be observed from the tabulated statement that the compressive strength of the different stones was also determined by Professor Elliot.

This latter test, as has already been stated, forms an unsatisfactory criterion of the merits of a stone for road making purposes. Indeed, if the compressive strength test were a good guide as to the suitability of any particular stone, flint roads should be the best. No doubt they are, so far as smoothness is concerned, but they will not stand the traffic which a road made of good basalt or syenite will carry well. Professor Elliot also examined the comparative absorption of different stones, after these had been immersed in water, with the results shown in Table XVII.

TABLE XVII.

Absorption Tests.

Material.	Hours soaked.	Per cent. absorbed.
Basalt A, B, and C,	72	Mere trace
Penlee stone,	78	,,
Clee Hill 'granite,'	72	,,
Clee Hill Dhu stone,	72	,,
Wicklow 'granite,'	78	,,
Guernsey 'granite,'	72	,,
Black limestone, Mumbles,	29	,,
Sweldon stone,	54	8·7
Cwymnofydd, Tongwynlais,	102	15·9

The amount of water absorbed is, of course, a measure of the liability of the stone to be disintegrated by frost, and the greater the amount of absorption, the less will the resistance of the stone be to this source of destruction.

These tests are interesting in so far as they relegate the limestones and sandstones to their proper place as a road material in comparison with the acknowledged superior qualities possessed by basalt and trap rocks generally.

140. It will be observed that the results obtained per cent. by the attrition or 'dry mud' test, correspond very nearly with the dry test for comparative toughness, carried out by Mr. E. J. Lovegrove, on stones of the same class, namely, Clee Hill Dhu Stone and Guernsey granite. The difference, however, between the amount of dust in the Hornsey experiments and that in the experiments carried out at Cardiff, shows that there was a less percentage in the former, notwithstanding that the samples of stone were subjected to 6½ hours' test by Mr. Lovegrove, and only four hours by Professor Elliot. The results obtained can be looked upon only as comparative, taken independently in each machine, and it is reasonable to suppose that the introduction of cast iron blocks into the 'tumbler' of the testing machine used by Professor Elliot would give a higher percentage of dust or 'dry mud,' than that resulting from the fixed angle-iron ribs in the cylinders of the testing machine used at Hornsey, with which the experiments were conducted by Mr. Lovegrove. An abstract of the results of these is given in the table on page 98.

141. Durability of Road Stones.—The best properties of a stone for macadam, as already mentioned, are toughness, hardness, and the power which a stone possesses of being able to withstand the weathering effect of atmospheric influences without undergoing disintegration. The conditions and circumstances under which the metalling is to be applied depend on the situation of the road and the class of traffic passing over it, and this

to a great extent should determine what will be the most suitable material under different circumstances for the efficient and economical maintenance of a road.

The durability of a road stone depends partly upon resistance to mechanical abrasion, and partly upon its power to withstand chemical decomposition. The resistance to abrasion depends mainly on the composition of the component minerals and the manner in which they are aggregated together into a compact mass, while the texture of the rock also enters largely into the question. The disintegrating effect, on certain stones, of the chemical influences met with on the surface of a road, is brought about by the decomposition of certain of the component elements causing the formation of a powdery clay. This is particularly the case with felspar, especially when the soda or lime varieties exist to any great extent. Biotite or black ferro-magnesian mica is of a very weak and perishable nature, and affects adversely rocks of which it is a component element.

The efficiency of igneous rocks generally depends on their compact granular texture. Those in which the grains are so small that they are barely visible, forming a continuous mass, cemented together in a siliceous paste, more or less compact, and having a high silica percentage combined with a sufficient quantity of ferro-magnesian constituents which tend to promote toughness, may be looked upon as satisfactory, being generally of a hard and durable nature.

Many minerals when exposed to the influence of air and water are liable to alteration as distinct from chemical disintegration, their durability depending on whether the power of cohesion is destroyed or otherwise. Rocks of a crystalline texture may be adversely affected by the decomposition of one of the component minerals; cohesion is maintained simply by the crystals being interlaced with each other or wedged together in mosaic fashion, as in the case of granites.

With some other rocks a more intimate union is observed, the crystalline grains are compactly set in a siliceous paste or matrix, which, by itself, is sufficiently durable to hold together and withstand chemical action, even should the crystals themselves be adversely affected and become decomposed.

Undoubtedly the best materials for producing the most durable metalling are basalts, diorites, and syenites; those having a fine texture and composed of minerals which remain unaltered when exposed to chemical influences give the best results.

Many rocks of the igneous series, however, show great variation, even when they are of an apparently hard and durable nature, decomposing and producing much dust in summer and a large quantity of greasy mud in winter. A trial should be made of the wearing qualities, under traffic, of each kind of stone of a doubtful character.

This is the only reasonable test which can be depended upon of

the fitness or otherwise of the material for the purposes of preparing macadam.

142. In localities where a suitable material of recognized quality does not exist, the hauling of a good class of macadam from a distance forms a large part of the total cost, amounting in some instances to 75 per cent. of the actual price per cubic yard of the material delivered, which limits and in many cases prohibits its use.

Under these circumstances the local material, whether it be of flints, limestone, gravel, or land-stones, is made use of, greater quantities being applied with a view to compensate for inferior quality.

This is probably, under the circumstances, the best arrangement to carry out, but it has the disadvantage of giving rise to large quantities of mud in wet weather, owing to the material being of a soft nature, which necessitates constant scraping. This also adds considerably to the cost of maintenance in comparison with the employment of material possessing better wearing properties.

143. Road metalling prepared from rock of a highly siliceous nature, but deficient in binding qualities, and which in many instances was eschewed on account of the stones becoming loose during dry weather, can now be advantageously adopted where steam-rolling is practised, the application of a suitable binding material overcoming to a great extent the inherent deficiency of the stone in this particular.

On roads over which heavy traffic passes, experience proves that by using the best material for repairs, although it costs more than a local stone of inferior quality, the ultimate expenditure will, taking all the varying conditions into consideration, be considerably less per annum. On roads which are not subjected to heavy traffic, metalling of a less durable nature may, under certain conditions, be employed, such as flints, hard limestone of a crystalline appearance, and millstone grit. These different kinds of material make very smooth and pleasant roads for light traffic, the limestone by itself or in combination with the flints, possessing the property of forming a mortar-like detritus which binds the stones together. Excessive moisture, however, produces much mud, necessitating constant cleaning, while during dry weather the surface is covered with dust and is liable to break up. The hardest limestones, often designated as granite, are considered in certain localities to have remarkable wearing properties, under moderate traffic. "Bristol Black Rock" is one of the class which is said to possess this quality, and it is further claimed that rock of similar properties is very hard to beat as a material for macadam. It should be remembered that the haulage and subsequent labour in the consolidation of the metal are nearly the same, whether the quality of the stone employed is of a superior or inferior nature. The actual cost of quarrying the stone in cases of extreme hardness or otherwise, forms, as will be explained later on, a mere fraction of the

ultimate amount necessary to be expended in constructing any section of road.

144. Comprehensive Road-Stone Tests to form Standard or Scale of Comparison.—Road-stone tests have occupied the attention of engineers and surveyors for many years past, but without any practical results of a comprehensive nature being achieved, although the time and labour bestowed on the matter have been considerable. The subject is of decided importance and one of growing interest, as evidence of which the exhibits of materials in connection with road making and the building trades, held periodically in London, may be mentioned. These exhibitions, besides being interesting, are of a highly educative nature.

Undoubtedly the problem is one in which individual knowledge of the wearing qualities of road metal in a particular locality may be tolerably accurate; nevertheless a ready and reliable method for selecting material from any source would be of great value.

Statistics, and also the tests carried out on road metal, show, however, that information on the subject, taken as a whole, has not made much progress in this country, more particularly as to the relative merits of the different kinds of rock and other materials used in road construction and repair, and to the connection between these and their mineralogical composition and wearing properties under the varying conditions met with in practice.

That tests are necessary for supplying the data for a definite scale which shall serve as a standard of comparison as to the relative value of different stones for road metal, is evident from the fact that any stone called granite is considered to be a good road material, although many granites in use are not of a durable nature. Similarly, many other rocks, notably elvans, basalts, quartzites, limestones, and some sandstones, although in many instances excellent material for macadam, are termed 'granite' as a trade name, while dolerite and diorite or whinstone are sometimes styled 'black granite.' These errors of nomenclature are very misleading, and a numerical scale or standard of comparison would, if introduced, relegate the different materials to their proper places, according to the chemical durability of the mineral constituents composing them, and the other properties which go to make a reliable road stone, whether these are igneous or sedimentary rocks, or chemical concretions.

The binding properties of many siliceous stones are deficient, but this defect, when the metalling is consolidated by steam-rolling, can be overcome by the judicious application of a suitable binding material.

Foothold and ease of traction might also be taken into consideration, and the former, especially in the case of basalts, demands some attention, when that material is used for repairs on roads having steep gradients.

All the methods of testing macadam by the several physical processes enumerated on pp. 96 to 102 inclusive are, taken exclusively by themselves,

misleading to a great extent, and in many instances do not agree with the behaviour of the material under actual traffic.

The standard of proficiency, for the best procurable stone, might be represented numerically by 1 indicating 100 per cent., and for limestones and sandstones 10, with a percentage which might vary from 50 to 20, according to the arrangement of the scale and the character of the materials embraced in it.

The real difficulty in arriving at this scale of comparison would be primarily in the selection of the best material obtainable in the British Isles for preparing macadam to withstand efficiently all the varying conditions which necessarily enter into the question.

The capability of road metal, taken as a consolidated mass, to withstand heavy and continuous wheel traffic during a long spell of drought without breaking up or splitting into minute pieces, and also of enduring a similar traffic during wet weather or alternating frost and thaw, cannot be easily determined. These are certainly the worst possible conditions in the actual wearing properties of any class of stone met with in practice.

Undoubtedly the position of a road, whether situated in the open or in a shaded locality, is a circumstance to be considered, while the foundation of the road, subsoil and surface drainage, as also level stretches and the gradients of roads, have all, more or less, an influence on the durability of macadam.

In the author's experience a road stone which is capable of resisting successfully a heavy traffic on a practically level road, the subsoil being of a retentive and naturally damp nature, does not give good results when applied in repairing roads on a gradient of about 1 in 25, by reason of the stones being split into small pieces by the wheels of vehicles during dry weather.

As an instance of this peculiarity, the macadam test, Nos. 6 and 8 in Table XIII., page 99, may be taken as a case in point; tests Nos. 3 and 4 in same table give satisfactory results on inclines, and on level stretches of road where a free subsoil and good drainage exist. In damp situations, however, especially when the surface drainage is sluggish, the metalling is not nearly so durable.

In addition to the value per cent. assigned to the different mineral constituents of which a particular stone is composed, the durability, and especially the resistance to chemical disintegration, should be particularly noted. Besides these qualifications it would be necessary to embrace, in the scale of merit, a value for attrition and absorption, and also for the crushing strength.

The latter test carried out on dressed cubes of stone, regardless of the texture and cleavage of the sample, fail utterly to convey any reliable information as to the comparative pressure-resisting properties of the different stones used for macadam. In estimating this factor it would be desirable, and certainly more conclusive, to test a given area of consolidated metalling,

as a square foot, for instance, which would determine the compressive strength, and therefore the comparative value of the material as applied and tested in practice by actual wheel traffic.

145. The different sources of supply of the igneous rocks and the other materials from which macadam and paving setts are derived, indicate their geographical distribution in the British Isles, as may be gathered from the following particulars.

In 44 per cent. of the fifty-two counties comprising England and Wales, there are granite, syenite, basalt and diorite (whinstone), while 90 per cent. have limestone of varying degrees of hardness; 8 per cent. have neither class of material for road purposes.

146. Scotland has only one county in which granite, basalt, whinstone or limestone are not found; the latter class of material is, however, only made use of to a very limited extent for macadam; the other rocks (especially whinstone) are abundant in most of the counties, and are generally of a superior quality.

147. In Ireland granite and whinstone are found in 37 per cent. of the counties, while limestone is found in every county except four, and in three counties there is neither class of material.

148. The syenitic-granite of the Channel Islands, especially that from Guernsey and Alderney, finds a ready market in London and many of the towns on the south coast; about 280,000 tons of finished material are shipped annually from St. Sampson's alone, of which about 30,000 tons are macadam, the remaining quantity being made up of channels, kerbstones, and paving setts. The absence of suitable material for preparing macadam in many of the English counties, and the appreciation or anxiety shown by those County Councils to obtain the very best material possible, has been the means of concentrating and extending the industry of quarrying and breaking stone for road purposes in localities where it is abundant, of recognized quality, and within reasonable distance of any of the ordinary means of conveyance, or connected directly by railway.

149. Among the principal centres of the quarrying industry in England and Wales for the production of macadam and paving setts, etc., the following may be mentioned:—

Clee Hill Dhu	(basalt)	Shropshire (supplied to 50 per cent. of the counties in England and Wales).
Rowley Hill	(basalt)	Staffordshire.
Penmaenmawr	('granite')	Carnarvonshire.
Pwllheli	(granite)	,,
Mount Sorrel	(syenite)	Leicester.
Stoney Stanton	,,	,,
Enderby	,,	,,
Nuneaton	,,	,,

Bardon Hill, Great Ayton stone	(basalt)	North of England.
Hartshill	('basalt,' quartzite)	Warwickshire.
Glyn Ruabon	(basalt)	Denbigh.
Portmadoc	(syenite)	Merionethshire.
Ceirog	(granite)	Chirk, North Wales.
Pennant stone		Glamorgan, Somerset, Pontypridd and Bristol.

150. The principal centres in Scotland of the granite industry in connection with supplying material for the making and repairing of roads and streets are Aberdeen, Cove, Kemnay, Peterhead, Dalbeatie, Bon Awe, Furnace Quarries (Loch Fyne), Kilsyth, and in Kincardineshire. Paving setts and kerbing are produced from these quarries in large quantities, and are much used in the principal cities of Scotland and in many parts of England. Road metal of this material, however, is used only to a limited extent, and that generally in the vicinity of the quarries mentioned. At times, however, a considerable demand exists for the better qualities of granite-macadam in some of the large towns within reasonable distance of the source of supply. Most of the counties are well supplied with suitable rock for producing road metal, such as basalt and whinstone, and the majority of the quarries are worked under the direct control of the County Councils. Previous to 1892, under the Road Trustees a similar arrangement existed, and was, until recent years, worked on the contract system at an inclusive price per cubic yard. Of late years, however, every effort has been made in many counties to secure the utmost economy by the authorities working their own rock-drills, and by the surveyors personally superintending the quarrying operations in their respective districts and counties.

151. In Ireland granite is largely quarried in the counties of Armagh, Down, and Wicklow, while basalt and whinstone are readily obtained and largely made use of for road purposes in the counties of Antrim, Donegal, Down, Londonderry, and Tyrone, limestone forming one-half of the material used for macadam.

152. As bearing on the subject of supply and demand for cheap and durable materials for macadamizing roads and paving streets, it seems strange that, with an abundant supply of suitable rock for the purpose, this country, especially the counties on the south and east coasts, is threatened with competition of a permanent nature for supplying these materials from France, Belgium, and Norway. As a matter of fact, there are annually imported into this country large quantities of Belgian and Norwegian macadam and paving setts, which, no doubt, are of good quality, while the price per cubic yard or ton is considerably less than for similar material from Mount Sorrel and the other quarries in Leicestershire. The effect of railway carriage on the price of these materials seriously threatens the stone industry of certain counties in this country, and any means by which the cost of land-carriage can be lessened, and

the working expenses reduced in the production of paving setts, and macadam for making and maintaining roads, should be carefully studied. Therefore, any expedient by which retrenchment, however small, is possible, should be practised by the judicious employment of modern plant and machinery for manipulating and transporting the material, and, no doubt, would result in large sums of money being saved.

It is estimated that $2\frac{1}{2}$ million tons of material are used annually for road stone and paving in these islands; the cost of the quarried rock alone amounts to about £130,000; while the value of the finished material is over half a million sterling.

CHAPTER V.

QUARRYING.

153. In the preceding chapter the quality of the rock necessary for preparing road metalling and paving setts has been explained. The methods of procuring or quarrying the material will now be described, while the cost of the operations, depending on many considerations, will be entered into in detail.

The igneous rocks are found in irregular masses and dykes, having innumerable 'backs,' or natural veins and fissures, interspersed through the mass, which facilitate its detachment from the parent rock; these rock masses exist to a depth practically limitless.

154. Opening New Quarries; Drainage; Gravitation.—In opening a new quarry the rock mass should be carefully examined with a view to taking advantage of the inclination of the bed joints, which, for economical quarrying, should dip towards the working face. The drainage of a quarry is also of great importance, and the floor level should, when practicable, be arranged so that the water can be drained from the working face by gravitation. The depth of the 'tirr' or overburden to be removed enters largely into the question of selection, and the amount of stripping necessary for a certain depth of rock face will in most cases determine the site of a quarry. When the overburden is deep, or forms a large proportion to the actual quantity of rock quarried, the cost of winning the stone will be correspondingly high. Gravitation, besides affording drainage facilities, assists to a considerable extent the process of quarrying and the removal of the material to the respective points at which it is to be treated, such as dressing-sheds and stone-breaking machines. By this means unnecessary handling is avoided, and economy promoted in carrying on the operations.

It is sometimes necessary, in order to secure the best quality of rock, as well as to limit the extent of the ground occupied, and also to economize stripping, for a quarry to be worked to a considerable depth below the natural surface. This at times may entail an expenditure for pumping water, in order to keep the floor of the quarry dry, while the lifting or

removal of the uarried material by mechanical means in the form of cranes and aërial cableways becomes necessary.

155. Tirring or Stripping.—The tirring or stripping may be removed as necessity arises, or, as in the case where the quarries are worked under County Councils directly, it may be accomplished by the roadmen during frost when their services can be spared from the ordinary road work.

The earth removed should be deposited at a point not likely to interfere with the future working of the quarry. Attention to this matter will save a considerable amount of trouble and unnecessary expense in lifting it again at some other time. The overburden, when of a tenacious nature, or when it is frozen, may be advantageously broken up by sinking a few holes from 2 to 5 feet in depth, and charging them with some high-grade explosive; on this being exploded the ground will be sufficiently broken up to ensure its easy removal.

156. The simplest form of quarrying is that by which the material can be removed from the parent mass by picks, wedges, and levers. This is, however, only possible in certain quarries, which are by no means numerous, and recourse must usually be had to drilling and blasting.

157. Hand-drilling or Boring.—The boring or drilling of holes by manual labour, or, as it is termed, *hand-drilling*, is generally effected by either single or double-hand operations. The jumpers, or boring-tools, are for the most part now made from cast steel bars of octagonal section, supplanting those formerly in use made from round iron bars with steeled cutting edges. The cutting edge of the tool may vary in width from 1 to 4 inches, the stocks being of a somewhat less diameter, so as to enable the tool to free itself readily in the bore-hole; this also avoids the introduction of any unnecessary weight into the jumpers.

158. For instance, a boring-tool having a cutting edge of 1 inch in width is made from a steel bar $\frac{5}{8}$ths of an inch in diameter, while $\frac{7}{8}$-inch bars are selected to make a boring-tool with $1\frac{1}{4}$-inch cutting edge, and so on in a similar proportion to tools or jumpers for boring a $2\frac{1}{2}$- or 3-inch hole, which are manufactured from bars of $1\frac{5}{8}$ inch in diameter. The cutting edge of the tool may be made straight or slightly curved for hand-boring; the straight cutting edge, although working more freely than those of the curved form, are somewhat weaker at the corners, and consequently liable to fracture.

159. Hand-drills and Jumpers.—The straight and curved cutting edges are shown in figs. 47 and 48, while fig. 49 represents a section of the chisel point, the sides of which should not form a greater angle than 70 degrees.

The steel bars from which boring-tools are made are generally cut into varying lengths as may be desired; the tools for boring holes of the smallest diameter are from 18 to 20 inches long, while those for boring holes of greater diameter may vary from 42 inches up to 6 or 7 feet in length. A blow given to a jumper is more effective the shorter the bar,

hence it is a common practice to make use of a number of tools, each succeeding one being somewhat longer, while at the same time the cutting edge is slightly reduced in width. The actual diameter of the hole drilled is somewhat greater than that of the drill-bit.

The striking face of the steel or stock should be flat, and in the larger sizes the diameter of the head is made less than that of the stock.

160. Hardening and Tempering Hand-drills.—The forging and hardening of boring or drill-bits are operations requiring much skill on the part

FIGS. 47–49.—Boring-tools.

of the smith, so as to avoid the cutting edge and lower portion of the stock being 'burnt,' or the formation of 'water cracks'; and in tempering it is advisable, in order to obtain the best results, to let down the steel to a bright straw yellow.

161. Hammers and Sledges.—Hammers or sledges of cast steel are made of varying weights, according to whether the drilling is to be performed by the single-hand or the double-hand method. These vary considerably in shape according to the ideas and customs of the workmen in the different localities where quarrying operations are carried on. The weight of hammers for single-hand boring is generally about $4\frac{1}{2}$ lbs., and as the expression implies, one man in a sitting position performs the whole operation by manipulating both tool and hammer. For double-hand drilling the sledge may be as heavy as 10 lbs., the shaft or helve, generally 30 inches long, being made of a wood having some elasticity, such as hickory, young oak, or acacia; ash is also much used for the shafts or handles of quarry tools.

162. Starting a Bore-hole. Single- or Double-hand Drilling.—The first step necessary in commencing drilling, after the tirring or stripping has been accomplished, is to fix the position of the bore-hole for blasting in the most advantageous manner, regard being had to the natural veins and fissures of the rock as a means of facilitating its detachment from the parent mass. It is necessary to remove any loose pieces of rock and prepare the surface by chipping, so that it may be nearly at right angles to the direction of the intended bore-hole. Double-hand drilling is sometimes performed by two men; one, sitting on the rock, guides and turns the jumper with one hand, and strikes, by means of a light hammer, alternate

blows, the other blows being delivered by a second man using a heavy hammer or sledge. The usual, and at the same time most satisfactory method, is for three men to do the work. One man takes up a sitting position and holds the drill vertically between his knees, keeping it in proper position, and turning it partly round, while the other two men strike the head of the boring-bar with sledges, lightly at first, and increasing the force of the blow after the bit has fairly entered the rock. The degree of turn necessary to be given in drilling is one-eighth of a revolution, which prevents the cutting edge falling twice in the same place; by this means the greatest amount of work is accomplished, and a circular form of bore-hole is ensured.

By using water in the bore-hole the drilling is greatly facilitated, the time being reduced by one-third; it also keeps the cutting edge cool, and converts the dust and chippings in the bottom of the hole into sludge, which must be cleaned out by means of a 'scraper' from time to time as it accumulates. In very hard rock a drill may have to be changed frequently, which necessitates the use of several of about the same length; and these should always be in good order and near at hand. The depth to which the bore-holes are drilled by the double-hand method is generally from 5 to 6 feet, sometimes 8 feet; for greater depths up to 10 feet churn-drilling is resorted to when the nature of the rock admits of this being done.

163. Churn-drilling.—The drilling-bar or steel for this method of boring has a cutting edge of different width at either end of the stock, the blow given to the rock being obtained by the direct impact of the falling drill, which is raised by two men to a height of about one foot, and then allowed to drop. In long boring-tools a sufficient weight for the purpose is generally

FIG. 50.—Long boring-tool.

contained in the steel stock, but additional weight may be obtained if necessary by having a bead or swelling fixed on the stock between, but at unequal distances from, the extremities, as shown in fig. 50.

164. The water which is poured into the bore-hole to facilitate the penetration of the bit into the rock is prevented from splashing about, particularly in shallow holes, by placing a perforated leather or india-rubber washer on the shank of the drill at the surface level of the rock. This object may also be accomplished by winding straw round the steel, which should be fixed as in the case of the washer.

The sludge formed during the process of drilling must be removed from time to time as the depth of the bore-hole advances, since the oftener this is done the greater will be the amount of drilling performed in a given time. The rock being exposed to the action of the cutting edge of the tool and the full effect of the blows transmitted to it by the jumper, will not be cushioned, as

it would be in the case where the sludge is lying between the bottom of the hole and the edge of the boring-tool. The cleaning out of the bore-holes, when not too deep, is effected by a simple tool called a *scraper*, which consists of a rod of iron varying from ¼ to ½ inch in thickness, and of a sufficient length to reach the bottom of the holes. It is provided with a disc attached at each end of the rod of different diameter, so as to make it suitable for the various sizes of holes bored. Instead of having discs at either end, one of these is sometimes formed with a spiral hook or *drag-twist*, which is very useful, as, by attaching a wisp of hay to it, the bore-hole can be thoroughly wiped dry previous to charging.

165. In the event of the shank of a drilling-tool or jumper being broken by some cause or other while boring operations are in progress, the portion left in the bore-hole may be recovered by various means. The simplest way of accomplishing this is to guide a running noose of cord by the aid of a second drill on to the broken one, and pull the noose tight, when the portion of the drilling-steel left in the bore-hole can be drawn out. Tongs having an arrangement attached for tightening the legs so as to grip the steel firmly are also sometimes employed for this purpose; while another instrument called a *beche*, made of iron, and having a hole at the lower end of a slightly conical shape, which fits on to the top of the broken steel, is at times made use of for the same purpose.

166. If, as often happens in many quarries from which road material is taken, water finds its way through fissures into the bore-hole, it becomes necessary to line it with clay when the explosive agent employed is blasting powder.

This is performed by putting the clay into the bore-hole in a plastic state, inserting an iron tool slightly less in diameter than the hole, and pointed at one end, called a *brill*, and by repeated blows forcing the clay into the joints and crevices of the rock. This instrument, which at one time formed an important part in a set of 'blasting gear,' has now become of less importance by the introduction of waterproof cartridges containing gunpowder, and the nitro-glycerine and gelatinous compounds, which are now much used in blasting operations.

167. Amount of Work accomplished by Hand-boring or Manual Labour.—The amount of drilling or the depth of holes which can be accomplished in one day will greatly depend on the hardness of the rock and the size of the drilling-tool used. Joints and fissures when lying at an angle to the direction of the bore-hole give considerable trouble, and much time is consequently lost, reducing the amount of work below what could otherwise be accomplished under more favourable circumstances. For this reason it is advisable to select the best possible position for the bore-hole, while at the same time due consideration must be given to its position and direction in relation to the portion of rock which is to be dislodged from the parent mass.

The amount of drilling which can be accomplished by hand, in the different classes of rock used for road purposes, varies considerably according to circumstances.

The method of calculating and stating the actual amount of drilling performed will be given in *cylindrical inches*, which is particularly applicable to open quarry work. This system of computing the amount of work done will also be adopted in determining that performed by machine rock drills, which will be described later on. The cylindrical inch has a relative value, and the use of the term is preferable when making a comparison of the amount of work done and the cost of the operation, than by simply stating the number of inches or feet in depth drilled each day. Under the latter circumstances no comparison is possible, as the width of the bit or size of the bore-hole may vary considerably according to the depth drilled, while the length of the working day is at times a variable factor in quarrying operations.

Therefore, by adopting this numerical figure as a standard for the amount of work performed in a given time, a comparison can be more readily arrived at between drilling by manual labour on the one hand, and that accomplished by a machine rock drill on the other, while the drilling capacity of the different types of the latter can also, by this means, be easily ascertained.

In Table XVIII. the average amount of work performed by hand drilling is stated in accordance with the preceding particulars. As the length of a day, however, is a somewhat vague definition of time, more especially when the working hours are interfered with by stress of weather, or shortened during the winter months, the hour is adopted from which a day's work of any specified number of hours can be calculated. The figures are taken from the results of actual experience under varying conditions, time being allowed for cleaning out holes and resting.

TABLE XVIII.

Rock Drilling by hand: one man manipulating the drill, two men striking with sledges. Bore holes vertical downwards.

	Cylindrical Inches.		
	Per Hour.	7 Hours Day.	10 Hours Day.
	No. 1.	No. 2.	No. 3.
In granite,	16	112	160
,, basalt,	19	133	190
,, whinstone,	21	147	210
,, limestone (mountain),	28	196	280

The depth of a bore-hole in inches, drilled in an hour's time, can be found by dividing the figures given in column No. 1 by the diameter in inches of the drilling-bit used. For horizontal or breast-holes the amount stated in Table XVIII. will be less by about 30 per cent. It should also be mentioned that the figures in the table are calculated for bits capable of drilling a bore-hole of an average diameter of 1½ inch; for shallow bore-holes of a less diameter, and which are at times required, the amount will be slightly in excess of the figures given.

168. Cost of Hand-boring.—To arrive at the cost of drilling per foot of depth with drills of varying diameters the cost of labour and incidental expenses require to be determined. Taking the average wages at 3s. 8d. for each man per day of nine hours, and allowing 2d. per foot of depth for sharpening the bits on the harder rocks, loss of weight in steel, repairs to hammers and sledges, etc., amounting to say 1s., 12s. will be the total cost for each day's work of one squad of drillers.

The cost of drilling one foot in depth with bits of different sizes, taking 12s. as the actual cost per day of nine hours, or rather over 1s. 4d. per hour, is shown in the following table, which may be taken as a broad average.

TABLE XIX.

Comparative Statement of the cost of drilling by hand per foot in depth with drilling-bits of varying sizes.

	Diameter of Bore-holes in Inches (average).									
	1½ in.		1¾ in.		2 in.		2½ in.		3 in.	
	s.	*d.*	*s.*	*d.*	*s.*	*d.*	*s.*	*d.*	*s.*	*d.*
Granite, cost per foot, . . .	1	6	1	9	2	0	2	6	3	0
Basalt, ,, . . .	1	3	1	6	1	8	2	1	2	6
Whinstone, ,, . . .	1	2	1	4	1	6	1	11	2	3
Limestone, ,, . . .	0	10¾	1	0	1	2½	1	6	1	9½

Should the total wages per day be more or less than that mentioned, then the figures in the table must be correspondingly increased or reduced, on the assumption that the same amount of work is performed.

When the nature of the rock permits of the bore-holes being put in by means of a churn-drill, the cost per foot, after the first 18 or 24 inches, can, by this method of drilling, be accomplished for about 20 to 25 per cent. less than the cost per foot stated in the table above.

169. The remarkable advance made in recent years in the construction of mechanical rock drills is such that the practice of hand-boring, the only method of former days, has been to a great extent superseded.

The practical advantages accruing from the use of rock-drilling machines in quarrying operations are decidedly great, while the rate of progress made possible by their use has been the means of reducing the cost of production, and greatly extending work in connection with the stone industry.

This applies very particularly to the quarrying of material for macadamizing purposes; and the substitution of mechanical power for hand labour in accomplishing this has been very marked in recent years, while the economy effected by its use enables the quantity of material for repairs amounting to double that possible by hand-boring to be procured for the same expenditure. In other words, the economy effected, on any quantity of material quarried, is 50 per cent. by machine over what can be accomplished by hand-drilling and the attendant expenses of blasting.

Machine rock drills are applied in a variety of ways, according to the work required of them; the arrangement with a tripod for its support will alone be described, as it is the only form employed in boring rock from which the material for making and repairing roads and streets is obtained.

Machine rock drills are actuated in the same way as the drills used in hand drilling, namely, by a succession of blows given to a chisel-pointed tool which is partially turned round between each blow as already described, and known as percussive boring.

170. Hand-power Drilling Machines.—Hand-power drilling machines have been employed to a limited extent; they are operated by two or three men turning a handle and flywheel conveying to the mechanism the necessary power to cause the drilling-bit to strike two or three blows on the rock for each turn of the handle. In this class of machine the force of the blow is limited, while a considerable amount of power is absorbed by the machine itself through the friction of its working parts. As a machine does not create power, a hand-power boring machine must be lacking in efficiency and economy. Although machines of this particular class have not attained a high reputation, still they may be regarded as the first step in the transition from hand to machine drilling. There can be no doubt that the Sommeiller drilling machine used for piercing the rock during the construction of the Mont Cenis Tunnel is the prototype of the rock drills now in use.

171. Different Types and Requirements of a Rock-drilling Machine.—The numerous types of machine rock drills in use at the present time vary in many particulars, but chiefly in the details of construction rather than in the principle on which they work. Durability is of great importance in a rock drill; any defect in the principle of the mechanism or construction of the parts subjected to considerable strain materially affects the working expenses. The weight should be reduced where not necessary for efficiency and the fitting of the working parts, an important element which may, if not properly designed and manufactured, involve the outlay of considerable expenditure for repairs. Great strength in certain parts of rock drills

is essential, considering the rough usage they are sometimes subjected to, while lightness for the sake of portability has also to be considered.

The requirements of a good machine rock drill are given concisely by André in his work on *Coal Mining*, and are as follows:—

1. A machine rock drill should be simple in construction, and strong in every part.
2. It should consist of few parts, and especially of few working parts.
3. It should be as light in weight as can be made consistent with the first condition.
4. It should occupy but little space.
5. The striking part should be relatively of great weight, and should strike the rock directly.
6. No other part than the piston should be exposed to violent shocks.
7. The piston should be capable of working with a variable length of stroke.
8. The sudden removal of the resistance should not be liable to cause any injury to any part.
9. The rotary motion of the drill should take place automatically.
10. The feed, if automatic, should be regulated by the advance of the piston as the cutting advances.

172. Tappet Drills.—From these exacting and admittedly necessary requirements it is evident that the movement of a valve actuated by a tappet situated in the cylinder of a drill does not conform with these rules, since two parts are subjected to violent shocks, namely, the piston and the tappet; moreover, the latter is liable to abnormal wear. Another defect which is invariably present in rock drills having a tappet-actuated valve motion is that the blow is struck on a cushion of air or steam. No doubt this may occur only to a limited extent if the drill operator is capable of judging the actual length of stroke, a qualification rarely met with in practice; while, on the contrary, there must be considerable cushioning. When this is the case the drill is expending the motive power on itself instead of on the rock. Tappets, especially those made of the double form, are liable to failure through fracture or displacement; it is therefore undesirable to use drills constructed on this principle at a high piston speed, and consequently they are not speedy cutters.

The tappet drill, however, has a slight advantage over drills with steam-thrown valves, especially when the steam is wet, or where by accident any foreign matter gains access to the working parts, the large openings in this class of drilling machines being capable of discharging these without injury to the valve.

With the inherent defects described, it is evident that the tappet drill cannot be classified as a perfect working machine.

173. Rock Drills with Steam-thrown Valves.—Those machines which

have steam-thrown valves with a positive action present the best form of construction, as only one part, and that part the piston, is subjected to violent shocks. Most of the earlier types of rock drills and a large number at present in use are distinguished by having a tappet-actuated valve, and, as might have been expected, the improvement in the valves of rock-drilling machines has tended in the direction of steam or air-thrown valves. Many other important features necessary to their efficient working will be noticed later on.

174. Some Types of Drills used in this country.—For obvious reasons it would be impossible to attempt a description of the numerous forms of rock drills constructed and made use of in this and other countries, although many, no doubt, possess points of considerable merit. Of those which have been in favour for some years past, the following may be mentioned: the 'Ingersoll-Sergeant,' the 'Hirnant' (Larmuth's), 'Schrams,' and 'Rio Tinto.'

The first two are those most extensively employed in this country, the former, in particular, being used by quarry owners and County Councils, while the latter has, in the past, been greatly used by contractors in connection with public works.

175. 'Ingersoll-Sergeant' Rock Drill.—The 'Ingersoll-Sergeant' rock drill with auxiliary valve is a development of the 'Ingersoll' and the 'Ingersoll Eclipse' drills, and has been designed for boring hard rock. The general construction and working parts are shown in longitudinal section in fig. 51. The main valve *a* is made of one piece in the form of a small double piston with two wide annular grooves turned in it to admit the steam or compressed air to and from the main cylinder *b*. The travel is produced by means of an auxiliary valve *c*, acting as a trigger to the main valve, but entirely independent of it. It opens or closes the steam or air passages, thereby releasing the pressure from one end or the other of the main valve. The auxiliary valve moves on an arc of a circle through contact with the piston *d*, operating tangentially, and which has a wide annular recess *e*, in the middle of its length, with inclined planes at either end, forming a shoulder. The valves are held in such a position that, while the piston carrying the cutting tool is moved towards the rock, the exhaust remains open at one end, the full pressure acting on the other end until the blow is struck, at which time, and then only, the main valve is immediately reversed. By the combination of the spool valve with an auxiliary valve, working in direct contact with the piston, a positive motion is obtained, which ensures the full force of the blow being delivered on the rock, or, as it is termed, a dead blow. This is a special feature of the 'Ingersoll-Sergeant' machine, and gives a distinct advantage compared with those drills which strike a cushion of steam or air in the front of the cylinder and the rock simultaneously, necessarily reducing the cutting power of the drill considerably.

The variable piston stroke, so essential in starting bore-holes, and when the bit is working through seamy rock lying at a considerable angle to the direction of the bore-hole, is obtained by simply turning the crank and feeding the machine towards the rock. This is of great importance, as by feeding the drill-bit up to within an inch of the rock a hole can be started with great ease, and in one-half the time occupied by a rock drill working on a full stroke. It may also be observed that in rock-drilling machines which have not a variable stroke, the bit is liable to have the corners broken by reason of the long stroke when striking on a slanting face. When this does not occur the bore-holes which are commenced under these conditions with a glancing blow, invariably drill a hole out of line with the machine, necessitating in most cases its being altered to coincide with the changed position of the intended bore-hole.

The liability of a drill-bit to stick or become jammed when passing through fissured rock presents itself in a greater or less degree in most quarries from which rock is obtained for road purposes. It is essential, therefore, that a drill should be capable of exerting sufficient power to loosen or withdraw the bit easily. This is provided for in the 'Ingersoll-Sergeant' drill by a sufficient annular space affording the necessary area for pressure on the front end of the cylinder, by which means it is capable of not only making the return stroke, but of lifting or recovering the drill-bit from broken, crooked, or muddy bore-holes. The piston, besides being made of steel and hardened, fits plug-like in the cylinder, and is provided

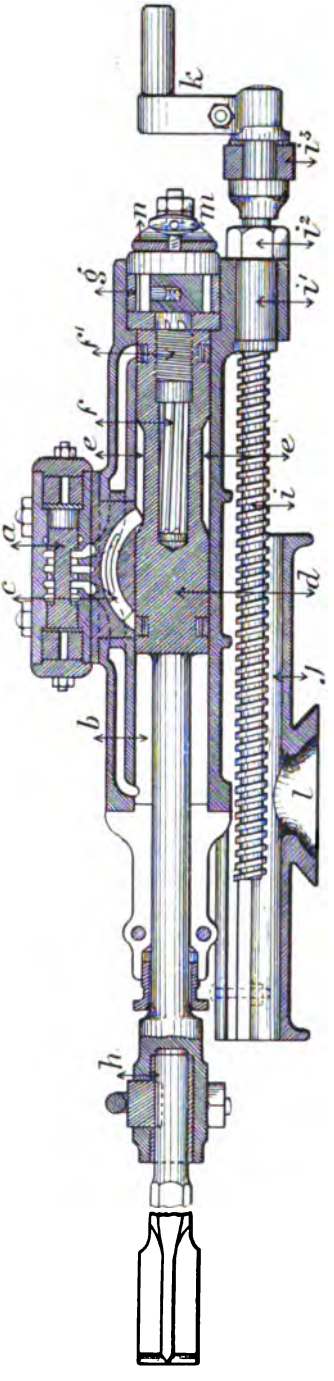


FIG. 51.—Ingersoll-Sergeant drill (longitudinal section).

with piston rings made in two pieces with an elliptical spring underneath to keep them tight to the bore of the cylinder, thus preventing leakage past the piston.

The means employed to give a rotary motion to the drill-bit on its return stroke is shown at *f* and *g*, fig. 51, and in detail at fig. 52, and consists of a rifle or spiral bar *f*, having deep-cut grooves working through a brass nut f^1 screwed firmly into the end of the piston, and fitted at the back head end with a ratchet wheel *g* with internal teeth. Two pawls, g^1, press against the ratchet teeth, and are kept in position by spiral springs having a straight line movement. It will be observed that the piston carrying the drill-bit assumes by this arrangement a new position after each stroke.

FIG. 52.

The drill-bit in striking an uneven surface has at times a tendency to turn the steel or shank in an opposite direction to that in which it should rotate. The liability to this in a drill with a rigid rotating mechanism may cause the spiral bar to become twisted and the ratchet teeth and pawls to break. In the 'Ingersoll-Sergeant' drill the effect of such a contingency is obviated by a release movement, brought about by the washer at the back head being simply turned round, thus overcoming the friction caused by the pressure of the back head springs. This device is undoubtedly an ingenious piece of mechanism, and being of decided efficiency, is not liable to injury, an all-important matter during drilling operations.

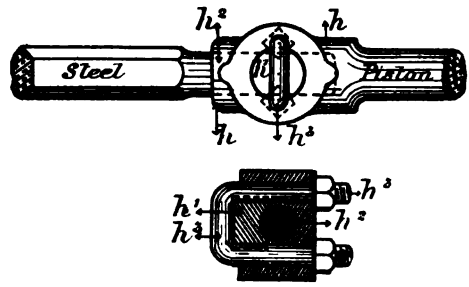
It often occurs in drilling rock that the bit, in passing through seams, encounters a soft part which causes it to penetrate suddenly, or advance rapidly, the result being that the piston strikes the front head of the drill. To obviate any possibility of damage through this cause two steel springs (*n*, fig. 51) are placed on the back head and connected with the front head by means of side bolts, thus cushioning the blow resulting from the drill operator neglecting to feed the machine properly.

This is at once a simple and thoroughly efficient method of preventing the breaking of the cylinder covers, and much preferable to and less expensive than the device generally adopted on many rock drills, where india-rubber buffers or cushions are made use of.

The manner of fixing the drill-bit steels is a matter of considerable moment, when it is considered that they have to be changed repeatedly during the progress of a deep bore-hole. The forward or feed motion of the drill described is 24 inches, necessitating the use of drill steels advancing in length by 2 feet. It will be obvious that should the time occupied in changing the steels be great, the time actually engaged in drilling by the machine will be correspondingly reduced.

It is therefore very desirable that the changing of the steels should

occupy as short a time as possible; hence the mode of fixing them should be simple; but as the vibration of the machine when at work and the strain on the drilling-steel is necessarily great, it is quite as important that the steel should be firmly fixed. The means of attachment is effected by inserting the end of the steel into a socket $5\frac{1}{2}$ inches deep and $1\frac{1}{8}$ inch diameter in the chuck end of piston, which is swelled out for this purpose. The arrangement of the chuck *h* is shown at figs. 53 and 54. The piston bushing is slotted, a round key h^1 fits into the slot and presses against the shank of the drill steel h^2, and the whole is held firm by a U-shaped bolt h^3. It is easily managed, while little time is necessary for loosening the two nuts, and for substituting one steel in place of another.



FIGS. 53, 54.

The forward movement is given by the feed screw *i*, which has a large square thread, working through a feed nut i^1, and having a binding nut i^2 in the cross-heads of the cradle *j*, by turning the crank handle *k*. The guides of the cradle are made square and of suitable dimensions; provision is also made for enabling any side play or slackness arising from wear being properly adjusted.

The machine is fixed on to the mounting or tripod by means of the conical spigot *l*, which is cast on the under side of the cradle.

The oiling of the valves and piston is provided for by an oil cup, placed between the throttle and steam-chest, the lubricant, preferably a heavy mineral cylinder oil, being thrown into the working parts in small quantities when necessary.

A small aperture with thumb-screw *m* at the back head provides for the oiling of the rotating mechanism.

From the preceding observations it will be readily understood that in a rock drill the positive valve motion, variable stroke, and effective rotation mechanism tend to give it efficiency in working and to promote economy in repairs. The 'Ingersoll-Sergeant' drill, according to André, fulfils in a remarkable degree the necessary conditions already alluded to, and it may therefore be looked upon as a nearly perfect rock drill. It is very compact, lightness and strength being a characteristic feature in its construction. These rock drills are made in various sizes, according to the nature of the quarry operations undertaken; the drill with a cylinder of $3\frac{1}{4}$ inches in diameter is a very serviceable machine and can be easily handled, as its weight is only about $2\frac{1}{3}$ cwts.; the tripod weighs $1\frac{4}{7}$ cwts., and each weight for the tripod, 1 cwt.

Bore-holes 14 to 16 deep can be drilled by this size of machine easily. It is the kind used in many stone quarries, and by the County Councils in Scotland. A machine for drilling deeper holes is also used in sale quarries, the cylinder of which is 3½ inches in diameter. This latter machine weighs 260 lbs. without the tripod, and can easily bore holes 20 to 25 feet deep, which in some quarries is a decided advantage.

176. 'Hirnant' Drill.—The other rock drill to be described is known as Larmuth's or the 'Hirnant' drill, a longitudinal section of which is shown in fig. 55.

The leading feature of this drill is, that the valve is actuated by a tappet rocking on a pivot, which works in contact with the piston. The valve box, which, in the earlier type of this machine, was made very long, has one of three arms of the tappet fitting into a recess in the valve spindle which carries the D-shaped valves. This arrangement, however, proved defective, owing to the breaking of the valve spindle by the sudden shock which it was subjected to when at actual work.

A shorter valve box is now substituted, the spindle dispensed with, and a solid piston valve *a* used in its place, obviating the defect existing in the former drill. The tappet *c* is, however, retained to ensure certainty of action and to lock the valve in position.

The piston *d* is turned to fit the cylinder *b* exactly, neither piston rings nor packing being made use of. The wearing of the piston and cylinder must in time admit of steam or compressed air leaking between them, but this does not materially affect the working parts, although its efficiency generally must necessarily be impaired. India-rubber buffers, *n*, are employed at either end of the cylinder to destroy the momentum of the piston in case of overshooting. When compressed air is the motive power employed to work this class of drill, these buffers wear quickly by being acted upon by the oil used in lubricating the cylinder, and when steam is used to operate it, the combined action of these destructive agents wears out the buffers quickly, and necessitates frequent renewals.

The action of a tappet-actuated valve, as already pointed out, must to a certain extent strike a cushioned blow, thereby expending a considerable amount of the force on the machine itself, instead of striking the rock directly. For the same reason, in a tappet drill a variable stroke can only be obtained by working on a cushion of air or of steam.

The rotary motion in the older type of this drill was obtained by means of a twisted square bar; this arrangement, however, not proving quite satisfactory, a grooved or spiral bar *f* has been substituted. This works through a nut in the back head of the drill, turning the cutting tool round at each stroke, and is secured by means of a ratchet and pawl *g*.

The feed or forward motion is provided for by a long screw, *i*, having a square thread passing through nuts i^1, and supplied with an arrange-

ment for taking up the wear. The method of fixing the cutting tool or steel to the lower end of piston was attained in the earlier machines by means of a bolt passing through the chuck in which the shank of the bit was inserted, and likewise through the steel itself, being tightened by a nut as shown at *h* in fig. 55. A new method of securing the drilling-bit is made by forming the shank with a taper and fitting this into a conical recess in the chuck end of piston, wedge fashion, as represented in fig. 56. This arrangement, however, is not satisfactory when drilling in seamy rock, as the steel works loose on being hammered, a process which is necessary under these circumstances.

The 'Hirnant' drill is constructed in a very solid manner, the object of the makers being steady and permanent work. It is not a fast boring machine in large or deep holes, and, generally speaking, requires few repairs. Very good work can be accomplished with this machine, providing the drill-runner exercises skill and intelligence so as to utilize the full power of the machine; if he works with a reduced stroke on a cushion of steam or of compressed air, he is simply spending power in pounding the drill itself instead of applying it against the rock to be bored.

The force of the blow in a tappet drill is materially checked by the too early admission of the steam or compressed air, which forms a cushion in front of the piston; the work accomplished will therefore be small in proportion to the power consumed, although the piston may be travelling at a great speed.

Greater skill is required for operating a 'Hirnant' drill than is necessary for working one on the 'Ingersoll-Sergeant' principle. There can be no question that

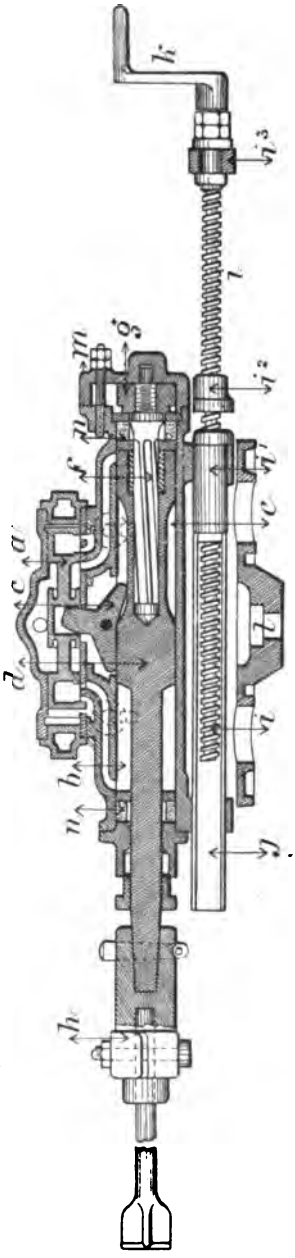


FIG. 55.—Hirnant drill (longitudinal section).

the results claimed for the 'Hirnant' machine have been attained, but the fact undoubtedly remains that rock drills which have a tappet action strike a blow on a cushion of air or steam, and, therefore, cannot deliver a dead blow. Further, a cylinder of larger size in proportion to the width of bit is required for drilling the bore-hole, or if it be of the same size, the cutting capacity must necessarily be reduced. The 'Hirnant' drill, notwithstanding the defects common to all drills of the tappet type, has been largely used by contractors in this country for tunnelling and other public works.

FIG. 56.

177. Compound Rock Drills.—The principle of expansion has been introduced for the purpose of further economizing the motive power in rock drills, but hitherto without much success. The difficulty has been the greatly increased size and consequently heavier machine necessary, which counterbalances the advantages which lightness gives for quick and easy handling. What may be gained in economy of power by compounding is lost in the time occupied in moving the heavier machine from one bore-hole to another. In addition to this the expanded steam frequently has insufficient power to withdraw the drill steel from a bore-hole, in seamy rock, without admitting live steam, thereby counteracting the benefit derived from compounding.

178. Tripods.—The support or mounting to which a rock drill is attached for the system of quarrying under review is that of a tripod, which constitutes a very important adjunct to the machine. For many reasons it must be of light weight for convenience in handling, and of strong construction, so that great rigidity may be attained. A point of the utmost importance is that it should admit of the drill being readily adjusted to any angle so that the holes may be bored in the direction and with the inclination required, and when so fixed permits of the feed or forward movement taking place.

It is also necessary that the tripod should be constructed so as to admit of its ready adjustment to the irregularities of the surface of the rock met with in quarry work. A drill support which does not possess these distinctive requirements is placed at a great disadvantage, and under certain circumstances may necessitate the employment of hand-boring to supplement the work done by the machine drill. It is obvious that a rock drill and mounting which cannot be so placed as to accommodate itself to the extreme irregularities of rock surfaces is placed at a disadvantage, and would under such circumstances be restricted in its operations as a labour-saving machine.

A rock drill may have a perfect valve motion, and be otherwise of good design, but may fail to do efficient work by reason of the defective

construction of the tripod, which incompleteness constitutes in many cases a serious objection to the adoption of a rock-drilling machine.

The form of tripod used in connection with the 'Ingersoll-Sergeant' drill is shown in fig. 57.

The saddle bolt *o* which carries the hip rings *p* and to which the legs are attached ties the whole appliance together, and by loosening it the legs of the tripod can be thrown into any position, at right angles to the bolt. The front legs *q* are further provided with a bolt *r* (attached to the hip ring), the loosening of which enables the position of the legs to be altered from that of a right angle to a parallel position in relation to

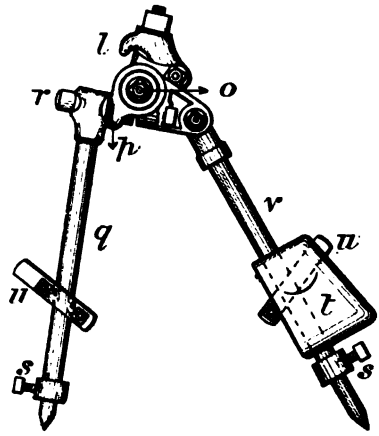


FIG. 57.—Tripod for 'Ingersoll-Sergeant' drill.

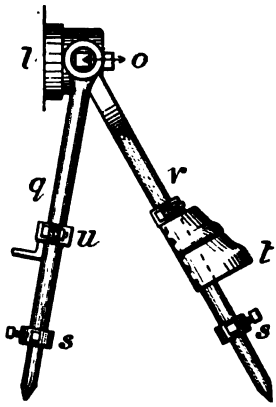


FIG. 58.—Tripod for 'Hirnant' drill.

the saddle bolt. The front legs *q* and back leg *v*, consisting of tubing, are pointed at the lower end; they are made telescopic and are provided with bands and set screws *s*, so that the legs can be adjusted to the irregularities of the rock surface.

When the machine is working the tripod should be perfectly rigid, for which purpose weights *t* are attached and kept in position by weight hangers *u* fixed to the legs at an angle as shown in fig. 57.

The arrangement of the tripod in connection with the 'Hirnant' drill, fig. 58, and indeed with most of the other types of rock drills used, is somewhat similar to that described, but the front legs *q* have only one movement, namely, at right angles to the saddle bolt *o*. In addition to this the use of slides and bolts greatly complicates and, at the same time, weakens the tripod, and naturally makes it non-efficient. By having an arrangement similar to that of the tripod for the 'Ingersoll-Sergeant' drill, and known as the universal joint, the drill can be so placed as to drill holes

in the most advantageous position for blasting, not attainable by other drills of which the tripods have only one movement.

The weight of the 'Hirnant' drill and tripod described is 3 cwts., and the three weights about 1 cwt. each. The cylinder is $3\frac{1}{2}$ inches in diameter, and can bore holes 10 to 12 feet deep, the width of drill-bit or size of bore-hole at commencement being $2\frac{1}{2}$ inches.

179. Drill-bits.—The width of the cutting edge, the form given to a drill-bit, and the diameter of the steel used, vary according to the nature and character of the rock to be bored and the capacity of the drilling machine employed. A judicious selection of the best shape of bit, suitable for the rock, adds considerably to the success of the boring operations with drills actuated by steam or compressed air. The chisel-pointed bit usually adopted in hand-boring has no place in machine drilling when the rock is fissured. A modified form of this kind of bit is shown in fig. 59; it answers very well for sandstone and slate of a solid nature. The flattened or grooved portion at the centre of the bit is made for the purpose of discharging cuttings and sludge.

The part forming the centre of any drilling-bit performs but little work, so that the reducing of the steel, as shown, does not affect its efficiency. The steels for the smaller sizes of rock-drills are generally made from $\frac{5}{8}$ths of an inch to 1 inch in diameter, while for the larger-sized machines the diameter varies from $1\frac{1}{8}$ inch to $1\frac{3}{8}$ inch. They are made from octagonal steel bars; the shank, or part which fits into the bush of the chuck at the end of the piston, is turned so as to fit it exactly, the top end being made of a hemispherical shape. The width of the cutting edge is determined by the size of rock drill used, that is, by the diameter of the cylinder, or in other words, by the force of the blow transmitted by the machine to the bit. It varies from $\frac{3}{4}$ of an inch to 3 inches for general quarrying, while in special circumstances it may be as wide as 5 inches. The proper shape to be given to a drill-bit, under varying conditions of work, is a subject on which a considerable amount of attention has been bestowed.

FIGS. 59–61.—Drill-bits.

The cross-bit shown in fig. 60 is a decided improvement on the older form or chisel-pointed bit, and does very good work in solid rock. There is, however, a difficulty with this form of cutting edge, arising from the circumstance that when rotated by means of the spiral bar it has a

tendency to strike the same place four times in each rotation. This unavoidable pounding of the drill-bit on the same spot, especially when it is penetrating the rock quickly, has a tendency to bury the bit in the same groove, with the result that the succeeding blows will cause the bore-hole to be 'rifled,' or of an irregular shape.

The drill-bit made in the form of an X, fig. 61, is now almost universally adopted with percussive rock drills, as from the shape of the cutting edge the chance of striking the same place is reduced by one-half; consequently there is less risk of the hole becoming rifled. Attempts to bore a round hole with the cross-bit have often failed, while the X-bit has performed the work satisfactorily in this respect. The drill-bit in cutting its way through seamy rock has a tendency to run out of line, or to follow the fissured parts, which may be at a considerable angle to the direction of the bore-hole. This causes great trouble, and may necessitate the work of drilling the hole being abandoned before the intended depth has been reached. It also entails a considerable loss of time in shifting the machine, and, if the abandoned bore-hole is not very deep, an additional one may be required to successfully carry out the blasting of the rock. It will be evident that under such circumstances the working expense in drilling on a certain piece of rock may be greatly increased from the cause mentioned. To obviate this, the drill-bits should be formed with shoulders or wings extending back to about 6 or 8 inches from the cutting edge, and only of a slightly reduced diameter at the rear end of the wings, so as to ensure free working. As the cutting edge wears in proportion to the amount of work done, it is advisable to have wings of the length mentioned.

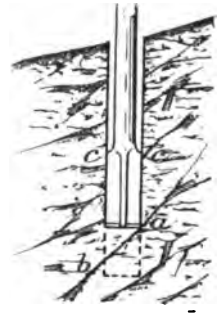


FIG. 62.

The purpose of these wings will be more clearly understood by referring to fig. 62. The cutting edge of the drill-bit, in penetrating the seams running diagonally across the hole, will, if not prevented, follow the line or vein *a b*. This is obviated by the wings being in contact with and guided by the sides of the bore-hole *a c* and *b c*, which check the tendency of the cutting edge of the bit to follow the slanting direction of the seamy or fissured portion of the rock *a b*.

180. Tempering Drill-bits.—The hardening and tempering of the drill-bits is a matter requiring careful study and observation on the part of the quarry smith. In hardening drill-bits, it is desirable to combine as far as possible the properties of hardness and toughness.

Hardness is produced by immersing in water a part of the bit, the steel of which should be of the best material, after it is heated to a certain temperature; this is the cooling medium employed, while toughness may be

increased by immersing the bit in oil, which process should be occasionally carried out to prevent the steel becoming too brittle. The drill-bits are first dressed to the proper form and gauge by means of special blacksmith's tools, viz., a dolly, sow, spreader, flatter, and swage. The quarry smith does not like to dress an X-bit, as that involves considerable trouble and manipulation; this difficulty may, however, be easily overcome by using two dollies. The drill-bit, when intended to be made in the form of an X, should be dressed first as a cross-bit; the requisite shape can then be obtained by spreading the wings with a hammer, and finishing it in the X dolly immediately before commencing the hardening process. The hardening of the cutting edge is proceeded with by heating the end of the steel to cherry redness, and then dipping it in cold water to a depth of about an inch, moving the bit at the same time slightly up and down to avoid the hardness terminating abruptly. When the requisite degree of hardness has been attained the steel is immersed in water until the heat is reduced sufficiently for tempering. The steel is then withdrawn and the colours carefully watched for, until that of a pale straw appears, which is the one most suitable for percussive rock drill-bits.

The temperature increases at the point, owing to the heat which is left in the stock passing down, the colours appearing in regular succession on the bright or filed surface of the bit. When the straw colour appears, which can be only properly observed in a dark place in the smithy, the steel is plunged into water and left there till cold, when the process of tempering is completed.

181. Motive Power.—The compressed air or steam is conveyed to the drilling machine by small iron pipes or gas tubing. When there is more than one drill at work, ⊤ branches are placed on the line of main pipe at suitable intervals, and laid to within a short distance of the drilling machines. The connection is completed by using a suitable length of seamless hose, preferably 5-ply, which will withstand the pressure of steam or compressed air; the exterior should be protected by being marline-wound, and each end should be provided with proper couplings for attachment to the piping and the drill. When it is necessary to connect two lengths of iron pipes for conveying the motive power which do not lie in the same straight line, a flexible ball-and-socket joint is employed, admitting of a movement of about 45 degrees in any direction.

By the use of one or more of these flexible joints on a line of piping many delays in changing pipes are avoided while they remain, especially Moran's patent joint, perfectly air and steam tight after many years' service.

182. Comparative Trials of Rock Drills.—Comparative trials of power rock drills have been carried out from time to time, but it must be confessed the results have been of little practical value. At the exhibition of Mining

and Metallurgy, held in the Crystal Palace, Sydenham, in 1890, a trial was carried out with power rock drills actuated with compressed air supplied at a pressure of about 60 lbs. per square inch, one of the conditions enforced being that the diameter of the bore-hole should be equal to half the diameter of the cylinder of the drilling machine. The blocks of stone operated on were faced so as to give each machine an equal opportunity in starting the bore-hole, two minutes being the time allowed to test the boring capacity of the drill. So limited a period of time for such a trial, be it observed, does not admit of any practical comparison being made between different types of rock-drilling machines. For instance, the drill-bit might not be properly hardened and tempered for the rock being operated on, and consequently the capacity of the machine would be determined by the suitability or otherwise of the condition of the cutting edge. As a rule the drill is applied in actual practice to a sloping, not a dressed face of rock, so that a drilling machine having a variable stroke could not show its efficiency to the same extent in the latter case as in the former. Rock drills were tried in Cornwall under the conditions given in the foregoing paragraphs, as long ago as 1867, and in an open quarry face ten years later.

The relative merit of a rock drill must of necessity be that of actual work accomplished, whether in a mine, heading, or open quarry work, and the capacity or cutting power and general handiness of the machine can only be determined by an every-day experience extending over a considerable period of time, and under the varying conditions which present themselves in quarrying operations.

183. Position of the Bore-hole.—The selection of the best position for bore-holes is a very important factor in quarry work, as the useful effect or result of the blasting operations depends on judicious choice in the location of a series of them. To determine the position of each bore-hole properly, it is necessary to consider what effect the action of an explosive will have in relation to the bore-hole and the bounding faces, and also to have a previous knowledge of the probable direction of the natural backs or fissures in the rock. The most favourable condition for blasting is when the rock presents an unsupported face on every side, but in ordinary quarry work this condition does not obtain, the wall or face of the rock being vertical or nearly so; only two free faces exist, namely, the top and breast of the rock. Under these conditions the bore-holes should be placed as nearly parallel to the longest free side as possible. The effects of disruption by blasting may be gathered from the line of fracture as shown in fig. 63, in which d, a, f represents the top of the rock, and $d\,e$ the face, while the bore-hole is shown at $a\,b$ and the explosive at c, w being the distance from the charge to the face of the rock or the line of resistance. The effect of the charge c when exploded, provided it be strong enough, is such that the lines of rupture will follow the bore-hole $a\,b$ and the

portion $w\,c$, while the dotted line f, b, e represents the probable crater. The distance w, or line of resistance, should not be more than three-fourths of the depth of the bore-hole, so that when charged the lines of least resistance from the centre of the charge c, $a\,c$, and $w\,c$ may be approximately equal.

Fig. 64 represents the plan of the top bench of a quarry; the face of the rock is shown at $b\,d$, and the bore-hole at a. The result of the blasting will depend upon the angle made by the lines of rupture $a\,b$ and $a\,c$, which must necessarily be less than 180°, and may indeed be a very small angle.

This would be the result if the shot-hole was fired singly, but experience shows that by firing several charges simultaneously, a greater useful effect is obtained. For example, consider another bore-hole the position of which is parallel to the rock face and placed at a'; the lines of rup-

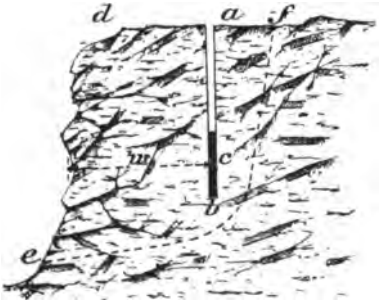


FIG. 63.

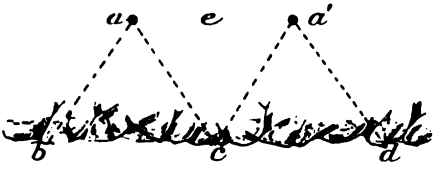


FIG. 64.

ture, taking them if fired singly, would follow the dotted lines b, a, c and c, a', d, whereas, if fired simultaneously, the mass of rock which would be dislodged is represented by the letters b, a, e, a', d. The distance between the points a and a' should not exceed the depth of the bore-holes, the best results being obtained when the distance between them is made equal to the line of least resistance w, in fig. 63. It will be seen that the useful effect is greatest when the disruption takes place at an angle of 180°, that is, when the lines of rupture run in opposite directions, showing the decided advantage which may be obtained by firing several shot-holes simultaneously. In firing single shot-holes, the useful effect diminishes as the angle made by the lines of rupture becomes less.

Briefly, these are the conditions necessary to be observed for the advantageous placing of bore-holes. As a mass of rock, however, is seldom homogeneous in composition or uniform in texture, a careful examination of the quarry is essential, so that the position and direction of the bore-holes shall be determined in accordance with these varying conditions, in order to produce a maximum effect with a given quantity of explosive.

Machine bore-holes may be drilled either in a vertical, inclined, or horizontal position.

The vertical position is the most convenient for quick handling and drilling, while in blasting, the explosive effect is wholly expended in shattering and dislodging the rock, none of it being required for lifting it. The face of a quarry, therefore, when of considerable depth, should be formed in benches, the level portions being from 12 to 15 feet wide. The depth of face may be varied according to the drilling capacity of the machine employed, the usual depth being from 14 to 20 feet, as shown in fig. 65; the dotted lines show the assumed line of the face as the quarrying operations are extended.

Horizontal, bottom, or breast bore-holes can be made with a modern rock drill. In many cases all these kinds of holes may be required in order to allow of the maximum quantity of rock being dislodged by one operation in blasting, and also of the bottom of the quarry being taken out in as uniform a manner as possible. In a quarry having a vertical face of from 20 to 22 feet, and operating with a drill capable of putting down 14-feet bore-holes, it becomes necessary to place horizontal holes at the floor level of quarry, so as to ensure the dislodgment of that portion of rock which is left beyond the crater formed by the blasting of the 14-feet vertical bore-hole. Vertical shot-holes require a smaller charge of explosive to dislodge a given quantity of rock, compared with that produced from a horizontal or breast hole, the reasons for which will be explained when dealing with the subject of blasting the shot-holes.

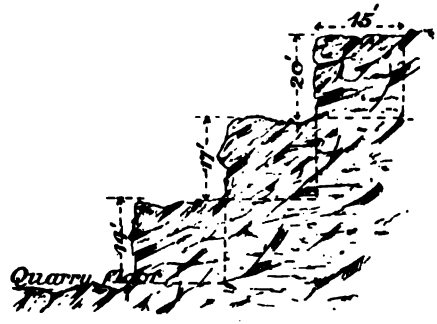


FIG. 65.

From the foregoing observations the position and direction of the bore-holes calculated to give the greatest useful effect in the blasting of the rock may be determined.

184. Previous to commencing drilling operations it is necessary to strip or lay bare such a surface-width of the rock as will remove all the tirr likely to interfere with the actual quarrying operations. The area to be stripped will depend on the quantity of material required, and on the height of the rock face. It may be determined by calculating the contents of the rock in the solid, allowing 13 cubic feet for each ton of material. In general, the stripping may be done as occasion requires, whether the quarries are worked constantly or interruptedly. The expenditure incurred in performing this work should be charged against the total quantity of rock removed from the area cleared. The cost of tirring or stripping per ton of rock obtained will

depend on the depth removed compared with that of the rock face, on the method adopted in removing the soil, and on the distance to which it has to be conveyed for disposal.

185. Examples of Quarrying taken from Actual Practice.—In the following example taken from actual practice the quantity of material required was 1500 tons, the depth of rock face being 20 feet; it was desired to determine what width would be required when the length of face is known. In fig. 66 the positions of the bore-holes are shown, Nos. 1 to 9 inclusive being vertical, and 10 to 14 horizontal or bottom holes, the length of face being 40 feet. These bore-holes were all drilled to a depth of 14 feet, and placed at an average distance apart of 11 feet, the measurement from the face of the rock to the first line of bore-holes being the same. The bore-holes in the second line were placed 9 feet further back and parallel with those in front. The distance from the face for stripping

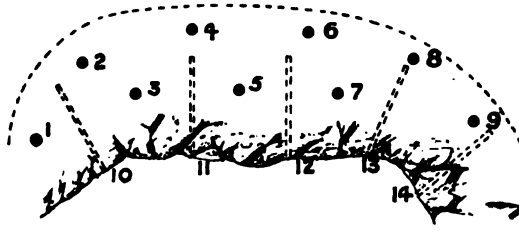


FIG. 66.

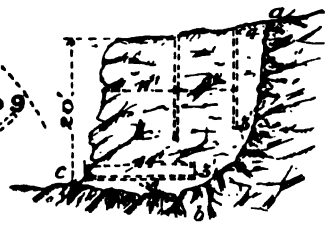


FIG. 67.

purposes is determined in the following manner: the total quantity of rock required is divided by the length of face multiplied by the depth of the rock, which in this case is about 20 feet. An allowance, however, must be made for the line of rupture extending beyond the position of the bore-holes, as the necessity of clearing the soil well back from this point to avoid its falling on to the quarried material is obvious; it is therefore advisable to make the width greater than the calculated figure by 6 or 8 feet. Fig. 67 is a cross-section of the quarry face, showing the position of the vertical and horizontal bore-holes; the actual line of rupture, or crater form, of the mass dislodged is shown by the line *a*, *b*, and *c*.

Fig. 68 is another example representing road-stone quarry No. 1, where the depth of the rock varied from 27 to 40 feet. In this case it was imperative to blast the total quantity required (4000 tons) at one operation, so that a system of bottom and breast bore-holes in conjunction with the vertical ones became necessary, whereas under ordinary circumstances it would have been worked in benches from the top of the rock surface downwards. It is usual to mark off roughly the area of the rock surface which must be operated upon to produce the quantity of rock required for a given length and depth of face. It will be observed that many of the breast and bottom

holes are shown at a considerable angle to the general line of the quarry face; this was necessary, owing to the position and varying direction of the veins and fissures running through the rock mass.

The bottom holes are indicated by the numbers 1 to 13 inclusive; the breast-holes, at an average of from 7 to 10 feet high above the floor level of the quarry,

FIG. 68.—Road-stone quarry No. 1.

are numbered from 14 to 22 inclusive, and the top or vertical holes, 23 to 42. Fig. 69 represents a cross-section at A A on plan, and shows the method adopted in arranging the position of the bore-holes. They were all put in 14 feet deep and charged with dynamite; the total quantity of material actually quarried and passed over the steelyard amounted to 4158 tons.

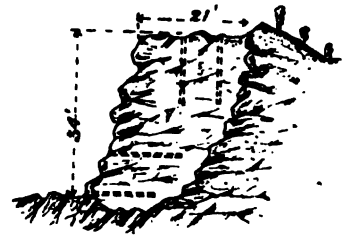


FIG. 69.—Cross-section of road-stone quarry No. 1 at A A.

There is no universal rule for placing bore-holes. The best plan is to study the conditions already mentioned, carefully note the position, depth, and direction of the bore-holes relatively to each other, and the results obtained from previous blasting operations. The number of bore-holes required will depend on the tenacity of the rock, on the development of the joint planes, and, in some measure, on the lines of fracture started by the preceding blast. With electrical firing, bore-holes can be placed further apart, consequently fewer are required to effect similar results.

186. In quarrying for 'dimension stones,' such as those used for kerbs, channels, and setts, the system of drilling few holes is usually adopted, but these are made deep and of large diameter, the object being to apply the blasting agent so that it will simply push the mass of rock outwards and yield the largest blocks possible. In obtaining materials for macadamizing purposes, however, it is of primary importance to reduce the mass of rock to a suitable size for handling; and therefore a large number of bore-holes are drilled, while the explosive used should be specially adapted for the end in view, which will be noticed under blasting.

187. Boring the Shot-holes.—The position and direction in which a bore-hole is intended to be drilled having been determined, the tripod is so placed that when the drill proper is attached and fixed to the saddle the chuck end of the piston carrying the cutting tool will coincide exactly with the spot selected for the bore-hole. In drilling vertical, and even at times bottom bore-holes, it is a common occurrence to encounter loose rock, which should be cleared away previous to fixing the position of the machine. The setting of the tripod for vertical holes is commenced by placing it in an approximate position with the saddle at a fixed height or distance from the rock. The irregular or rough nature of the surface may necessitate placing the legs of the tripod at different angles and of varying lengths. This is readily accomplished by means of the saddle bolt, front leg bolt, and the telescopic pointers fixed by bands and screws. A small hole is made in the rock at three points with a chisel or quarry pick for the pointers of the tripod to sit in. The jaw of the saddle at the apex of the tripod is loosened, and the conical spigot attached to the cradle of the drill is then placed upon it, and properly secured.

The position and direction of the bore-hole are then definitely fixed, all the bolts of the tripod being tightened, and the weights placed on the legs by means of the hangers or clips, which keep the drill perfectly rigid when working. Fig. 70 shows the machine drilling a vertical hole.

In drilling bottom or breast-holes the tripod legs are placed so that they are in a flat position, the under part of saddle resting on a block of wood. The pointers of the two front legs are placed against the rock face, while the other, or back leg, is placed directly behind the line of the bore-hole to be drilled, and is prevented from receding, by reason of the action of the drill, by wedges or by a heavy block of stone.

The weights are fixed on all the legs in a manner similar to that adopted in drilling a vertical bore-hole.

Fig. 71 shows the machine drilling a horizontal or breast-hole.

The first length of steel is then placed in the recess or chuck end of the piston, and properly tightened by means of the U-bolt and nuts. This operation has to be performed as each succeeding length of steel is required.

The connection between the pipes conveying the motive power, whether steam or compressed air, is made by a suitable length of heavy hose marline wound for the former, and wire armoured when compressed air is used. Before attaching the hose to the drill it is advisable to turn on the steam or air temporarily, and clear out any foreign matter which may have by accident gained access into the feed pipes or connections, thereby minimizing any chance of injuring the working of the valve. In commencing the drilling of a bore-hole, whether the rock is at right angles or in a slanting direction to the axis of the drill-bit, it is advisable to go slow at first; this is accomplished by feeding the machine with the cutting tool up to within

FIG. 70.—Machine drilling vertical bore-hole. [*To face p. 138.*

FIG. 71.—Machine drilling horizontal or breast bore-hole. [*To face p. 138.*

an inch of the surface of the rock by means of the feed screw. As the rock is penetrated the stroke is lengthened, and the force of the blow increased so as to attain the full drilling capacity of the machine; the length of stroke varies in different rock drills, that of the 'Ingersoll-Sergeant' being from 6 to 7 inches.

In tappet-actuated valves the stroke may be shortened to about 4 inches by working on a cushion of steam or compressed air in the cylinder, the full stroke of the drill, the valve of which is operated by this means, being 7 inches. The variable stroke alone constitutes a very great advantage, and a rock drill possessing this property will start a bore-hole in half the time required by one working on a longer stroke. Again, a perfectly straight bore-hole is also easily made with a machine having a variable stroke. Another advantage possessed by a rock drill with a variable stroke is that the stroke can be shortened should a bit become accidentally fixed. Many of the different types of rock drills work at a pressure of 40 lbs. to the square inch, but the 'Ingersoll-Sergeant' drill, when working at a pressure of from 70 to 80 lbs. per square inch, will perform a greater amount of boring in proportion to the difference of the pressure stated. The oiling of the valves and piston is effected after the drill has been at work some little time, and when the condensed steam is got rid of, the oil being applied in small quantities at frequent intervals. The piston should be kept thoroughly lubricated, in order that the friction in the stuffing-box may be reduced to a minimum.

The feed or forward movement is regulated by the feed screw, and depends on the rapidity with which the cutting edge of the bit penetrates the rock.

It is essential to expeditious boring that the drill-bit, except in starting a bore-hole, should be fed just fast enough to give the piston its full stroke. When fed too slowly it will strike the front head, and if too fast, the useful effect of the cutting tool is reduced, and the power expended on the machine itself instead of on the rock. The depth to which a bore-hole should be drilled will depend greatly on the size of the rock drill employed and the class of work undertaken. For holes 20 feet deep, experience shows that the best results are obtained with a machine having a cylinder $3\frac{1}{2}$ inches in diameter. The hole is commenced with a drill-bit having a cutting edge 3 inches wide, and is finished at the depth stated with a $1\frac{3}{4}$ inch bit.

For general handiness, where manual labour only is available for handling the machine, weight being an influencing factor for expeditious work, a drill having a cylinder diameter of $3\frac{1}{4}$ inches, and capable of boring holes to a depth of 14 or 16 feet, is to be recommended. With this size of machine a bore-hole is commenced with a diameter of $2\frac{1}{2}$ inches, and finished at the depth of 14 feet with a drill-bit $1\frac{3}{4}$ inches across. This depth and diameter

of bore-hole admits of a large mass of rock being easily dislodged by means of high-grade explosives and electric blasting.

The feed or forward movement of this class of drill is 24 inches, consequently with each succeeding length of steel there is an advance of two feet until the desired depth is reached. The condition which the cutting edge of the drill-bits will present after boring 2 feet will depend on the hardness of the rock, and on the care exercised in hardening and tempering them. In average whinstone, and even in granite, a drill-bit if properly dressed and tempered may be used a second time, and in many instances one drill-bit has been used in boring 6 feet,—that is, made use of three times before being returned to the smithy to be re-sharpened.

It is a remarkable fact that the wear of the cutting edge of a machine drill-bit working in hard rock will, for a given amount of boring, be only $\frac{1}{4}$ or $\frac{1}{6}$ that of a hand-boring bit. Keeping the bore-hole clear of the chippings is a matter requiring some attention, the actual amount of boring being increased at least 30 per cent. by using water in the bore-hole; this also serves the purpose of converting the dust into sludge, which can be readily removed by the 'scraper.' A much better and at the same time quicker appliance for removing the sludge, is the small pump shown in fig. 72, having a ball or catch valve working at the bottom end of the pump, which allows the liquid to be forced up the tube

FIG. 72.—Bore-hole pump.

to a certain point, on the return of which the valve falls and retains the contents, which are then removed from the bore-hole. A piece of $\frac{1}{2}$-inch iron rod is attached to the pump and forms the handle; it should be of sufficient length to easily reach the bottom of the deepest bore-hole. The pumping is performed at each change of bit; it is necessary at times, however, to remove the steel and clean out the bore-hole before the drill-bit has penetrated the rock to its full length; but as this involves an unnecessary loss of time, such delay should be avoided by keeping up a good supply of water. When the débris formed by drilling is of a viscous nature and adheres to the steels, it may be advisable to direct a jet of steam through a small piece of piping inserted into the bore-hole and attached to the steam hose; this will effectually clean out the sludge when other means fail.

When the steel sticks in boring through seamy rock it may be relieved by striking it with a light hammer; but care must be exercised to deliver the blow on the stock of the drilling-bit, and not on the piston or chuck. If the rotating mechanism fails to operate after the drill-bit strikes a blow, the

cause will invariably be a want of pressure on the washer at the back head of the machine. This can be quickly remedied by tightening the nuts of the side bolts, which will cause the back head springs to press firmly on the cap.

188. Work done by a Rock Drill.—The amount of work which can be accomplished by a rock drill in one day or in any given time, depends on the capacity of the machine itself, the nature of the rock to be bored, the manner in which the drill-bits are formed and tempered, and the size or diameter of the hole drilled.

In hard solid whinstone, two feet may be penetrated in five minutes with a drill-bit having a cutting edge $2\frac{1}{2}$ inches across. As each drill-bit has, however, to be replaced by a longer one for every two feet drilled, and the bore-hole also requires to be cleaned by pumping, some time must be allowed for this, say from three to four minutes for the combined operation. Starting with a drill-bit $2\frac{1}{2}$ inches in diameter, a depth of 12 feet can usually be accomplished in an hour, including the time required for changing the bits and pumping out the bore-hole.

As the machine has to be changed from one point in the quarry to another as the boring proceeds, the actual time occupied in drilling is even less than this, especially when shallow bore-holes only are resorted to.

The actual work done in a day of nine hours will depend on the number of times the machine is changed from one point to another, and on whether the nature of the rock is solid or seamy. The time occupied in changing the machine and starting another bore-hole will depend to a certain extent on the distance to which the drill may have to be taken, and on the irregular nature of the rock surface. It is also contingent on the aptitude of the drill operator. The average time required is from 10 to 15 minutes.

It is obvious that when the machine has to be removed often during a day's work, the time so occupied will bear a considerable proportion to the time actually expended in drilling.

Taking all these circumstances into consideration, it will be evident that no criterion as to the capacity of a rock drill can be formed by simply putting it to work on a block of stone for a few minutes. A complicated machine might do good work in a short space of time, and yet be entirely useless for practical work. All those who are interested in quarrying operations should consider this matter carefully, and adopt those machines only that are made on proper principles, and are capable of withstanding the usage of actual work.

The actual amount of boring which can be performed in a given time either for comparison, or in order to determine the cost per lineal foot of hole drilled, can be arrived at only by averaging the day's work over a considerable period of time. In solid rock the author has, with an 'Ingersoll-Sergeant' drill, bored 70 feet of vertical holes in one day of ten hours; this is, however, too

great an amount of work for every-day practice, as in boring through fissured rock, the actual performance may only amount to 35 feet, and even less in extreme cases.

The experience gained in working this particular type of rock drill for a number of years, taking all classes of rock into consideration, and working under varying conditions, shows that the amount of boring which can be accomplished averages 42 feet per day of nine hours, each hole being of an average depth of from 10 to 14 feet, the cutting edge of bit used being $2\frac{1}{2}$ inches across the mouth, and finishing at the bottom of a 14-feet bore-hole at $1\frac{3}{4}$ inches, or an average diameter of $2\frac{1}{8}$ inches. In calculating the amount of work done, either by hand or by machine drills, it is advisable to follow some standard in determining the amount of drilling performed, so that a comparison may be made of the relative merits and drilling capacity of manual labour, and of the different types of rock-drilling machines in use. The cylindrical inch of hole bored, previously mentioned, affords a ready means to this end, and when applying this method in calculating the results of an average day's drilling, namely, 42 feet, it will be found that this amounts to 1071 cylindrical inches of hole bored, or 119 per hour. These figures include the time occupied in removing the machine from one point in the quarry to another, changing the steels, and pumping out the bore-holes. As already stated, a 12-feet hole may be drilled in one hour, including, of course, the necessary time for changing bits, etc.; this amounts to 315 cylindrical inches of hole bored in that time. From these results it is evident how essential it is to drill deep bore-holes, in order to avoid the delay occasioned by the repeated changing of the machine, during which time the drill is not working. In the event of bore-holes of shallow depth being adopted, as is sometimes done, it is very evident that changing the position of the machine repeatedly will occupy nearly as much time as the actual drilling, in which case the least possible advantages are attained by employing rock drilling machines.

The means by which rock drills are actuated, as already mentioned, is compressed air or steam. In large quarries where boring operations are carried on during the greater part of the year, and probably employing a large number of drills, the most suitable and economical motive power is compressed air, which, besides these important considerations, serves as a means of preserving a clear atmosphere at the working face, and adds considerably to the best possible conditions for carrying on the operations.

In establishing a compressed air plant it is necessary to supply a compressor capable of providing a sufficient pressure for the number of rock drills which may be at work, the air being conveyed in pipes of relatively large diameter. By using compressed air as the motive power for rock drills, it is immaterial at what distance the compressor is situated from the point where the drilling operations are being carried on, as, provided there is no

leakage, the pressure of the fluid working the drills is practically the same as at the compressor. In other words there is little or no loss of pressure between the point of compressing the air and that of using the compressed air.

In quarries where the work is carried on in an intermittent manner, such an expensive plant as has been described, while possessing many practical advantages, could not be economically employed. It is necessary, therefore, to make use of a boiler to generate steam for actuating the drill or drills. The most serious objection to the use of steam for this purpose is that at certain seasons, owing to the humidity of the atmosphere, the steam hangs about the working face, and greatly impedes the movements of the workmen.

A boiler generating steam, to be of any practicable use for such work, must be placed as near as possible to the point at which the drill is working, so that the steam may be had as dry as possible. If the distance between these two points be great, the steam in going through the long line of pipes becomes condensed, which, combined with the less effective pressure, places the working of the machine at a great disadvantage. This points to the necessity of the boiler being placed on wheels, so that it can be readily run from one point to another along the quarry face.

The pipes conveying steam as a motive power should be of as small diameter as is consistent with the work to be done, as the condensation on a large surface would be prejudicial to effective and economical working.

In quarrying rock for road purposes the usual, and, in fact, the only suitable way of providing the motive power is by means of a road or traction-engine, which, besides supplying the requisite steam for operating the drill, can be utilized for removing the drilling plant, and sleeping van for the use of the workmen, from quarry to quarry as occasion requires.

The connection with the boiler should be so placed that the steam for working the drill may be had as dry as possible. It is advisable when the drilling plant is once started in a quarry, although only a small quantity of material may be required, to drill a sufficient number of bore-holes which can be blasted from time to time as necessity arises. The reason for this is, that to change the plant from one quarry to another every day or second day increases the cost of drilling operations considerably, by reason of the time occupied in travelling between the different quarries. It will be apparent that the cost of drilling may be increased to twice what it should be by unnecessary changing from quarry to quarry, involving in some instances a whole day, before a sufficient amount of actual work can be performed in proportion to the time occupied. In other words, the time occupied in travelling to a quarry for one day's drilling, which may be sufficient in order to produce the requisite quantity of material for immediate purposes, will involve an increase of cost compared with the same time and expenditure spread over a working period of from one to three weeks' duration.

189. Blasting.—In the foregoing pages the tools and machines used in rock boring, and the conditions necessary to be observed in placing the bore-holes, a matter of the highest importance, have been considered; it now remains to describe the methods adopted in charging and firing them, and the different kinds of explosives used for this particular class of work.

When it is advisable to simply rend the mass of rock so that blocks may be obtained as large as possible, it is necessary to make use of an explosive having a comparatively slow action. In the case of procuring material for road metal quite an opposite effect is desirable, pointing to the necessity of employing an explosive having an extremely rapid and violent action, which will shatter the mass of rock sufficiently, and obviate, as much as possible, the necessity of after manipulation.

In blasting rock from which dimension stones are to be produced, gunpowder is sometimes used; but special qualities of blasting powder are manufactured to suit the nature of the rock and the class of work for which it is intended.

190. Gunpowder as a Blasting Agent.—Gunpowder, the grains of which are small, is more rapid in action than coarse-grained powder; the explosion of the latter is adopted to simply rend and, by its slow moving and accumulative force, dislodge the mass of rock. Gunpowder is termed a direct explosive agent, that is, its force can be developed by direct means, such as ignition; it can also, however, be detonated by indirect means, which materially increases its explosive effect.

The composition of the blasting powder generally used in Great Britain is 75 per cent. saltpetre, 10 per cent. sulphur, and 15 per cent. charcoal. Dynamite of a low grade, or containing a small percentage of nitro-glycerine, may be adopted with advantage at times for blasting rock under similar conditions.

191. High-grade Explosives.—The high explosive effect necessary to shatter the class of rocks used for macadamizing purposes, such as whinstone, is best obtained with high-grade nitro-glycerine compounds, fired by electricity. These high-grade explosives are termed *indirect* explosive agents, as they require an intermediary, such as a fulminate detonator, to cause them to explode properly.

192. The nitro-compound explosives of high grade are:—

Blasting gelatine No. 1, which contains	94	per cent.	nitro-glycerine.
Gelatine-dynamite,	,,	74	,,	,,
Gelignite,	,,	62½	,,	,,
Dynamite, No. 1,	,,	75	,,	,,

Blasting gelatine is composed of collodion cotton, which is transformed into a jelly-like mass by being acted upon and dissolved by the nitro-glycerine.

Dynamite is composed of nitro-glycerine and a diatomaceous earth called

'Kieselguhr' or earth meal, found in some of the moors in Scotland and in Germany.

Blasting gelatine has an explosive energy 12 per cent. greater than dynamite; but its action being slower, the effect is much less shattering. It is specially adapted for rending tough rock and dislodging it in large masses. Dynamite being a rapid and violent explosive, produces its effects very suddenly, and is therefore better adapted and fulfils the conditions necessary for supplying material for macadamizing purposes by dislodging and reducing the rock to a size which saves subsequent sledging; consequently the cost of quarrying is lessened.

If blasting powder is used in preference, or through some conservative idea that its effects are better in comparison with those of the nitro-glycerine explosives for a similar purpose, it is necessary either to make larger bore-holes or to increase the number, to obtain corresponding results.

It will be evident that in drilling bore-holes purposely to make use of blasting powder as the explosive agent, the cost of boring is unnecessarily increased.

From these observations it is obvious that the most economical results are obtained by drilling deep bore-holes with a rock drill, and employing high-grade explosives to dislodge the rock operated upon, so as to reduce it to suitable dimensions.

193. Different Explosives in relation to Wet Bore-holes.—In quarrying operations wet bore-holes have to be contended with, according to the season of the year in which the work is carried out. In such circumstances, blasting powder, unless in waterproof cartridges and used without stemming in the bore-hole, is not permissible, as moisture detracts from, and in most cases destroys, its usefulness as an explosive agent.

Dynamite when retained in the parchment covering is not liable to be thus affected, but in 'pressing home' this explosive in a bore-hole the effect is to considerably alter the form of the cartridge, exposing the dynamite to the action of the water, when it exists. In charging the shot-holes under these conditions the nitro-glycerine exudes from the 'Kieselguhr,' which greatly impairs its explosive effect. In extreme cases where an accumulation of water in a bore-hole is such that the dynamite might be materially affected, it is advisable to use blasting gelatine, as this form of the nitro-compounds is practically unaffected by water.

The relative cost of the different kinds of the nitro-glycerine class of explosives may determine to a certain extent which of them should be employed in particular circumstances. Nobel states that dynamite is about six times, and blasting gelatine nine times, as strong as blasting-powder.

194. Conditions and Peculiarities of High-grade Explosives.—Dynamite may be 'too dry,' owing to a deficiency of nitro-glycerine in the absorbent; it may also be over-saturated, when the cartridges will feel

greasy to the touch, which may be caused by storing the explosive in a badly ventilated place. In the former case the effect of detonation may only cause a partial explosion in the bore-hole, while the residue will simply burn away, and give off very foul gases. Dynamite, and the other nitro-glycerine explosives, should be in a plastic state when placed in the bore-holes; they have the disadvantage, however, of freezing at a comparatively high temperature—dynamite losing its plasticity at 40° F., while blasting gelatine becomes insensitive at a temperature of 45° F. It may take days to thoroughly thaw frozen dynamite, while, on the other hand, it may be exposed, when soft, for days to a temperature below 32° F. without losing its plastic condition.

Frozen dynamite requires a high initial detonation to explode it, and when in this state it is somewhat dangerous, owing, it is believed, to the breaking of the crystals causing some peculiar molecular action, which at times has brought about accidental explosions.

Special warming-pans are provided for thawing frozen dynamite, or even when it is in a slightly hard state; the process, however, is a slow one when large quantities of explosives have to be treated. The warming-pans consist of two galvanized zinc vessels, one inside the other, the interspace being filled with hot water and protected on the outside with felt to retain the heat. The frozen explosive is placed in the centre and covered with a lid; these warming-pans holding, according to size, from 2½ lbs. to 5 lbs. It is essential that the inside of the warming-pans be kept thoroughly clean, so as to reduce any possible chance of danger to a minimum. When repairs are necessary, the parts should be previously washed with a solution of 2 parts of caustic soda and 2 parts of alcohol to 96 parts of water, so that any nitro-glycerine which may be deposited in the crevices will be destroyed.

It is very difficult to keep the explosive which has been thawed in a thoroughly plastic condition, until the requisite quantity is so treated, previous to charging the bore-holes. Especially is this the case during cold weather in open quarry work, removed, as is usually the case, from any kind of shelter. A very speedy and effective method of thawing and keeping nitro-compounds in a plastic condition for immediate use may be carried out in the manner described in par. 195, and when ordinary care is exercised, little or no fear need be apprehended as to the results. It must, however, be remembered that these explosives detonate when heated above 356° F., and that chemical changes take place in dynamite above 158° F.

195. Warm stable manure is spread to a depth of one foot on the ground, adjacent to the quarry where the blasting is to take place, and of a sufficient area to accommodate the quantity of explosive necessary, allowing a free space between the boxes. The boxes, which contain 50 lbs. of explosives each, are then placed on this layer, and the lids partially opened, when a quantity of manure is spread over and between them, and allowed to remain until the explosive material is thoroughly thawed and in a plastic

condition. Care should be exercised to avoid a high temperature, as already explained, for which purpose a thermometer may be advantageously applied at several points to ascertain the maximum heat, and, when necessary, the heat can be reduced by removing some of the manure.

196. Determining the Charge.—It is a somewhat difficult matter to calculate exactly the amount of explosive necessary to effect the purpose intended. The conditions may vary considerably at each bore-hole; the natural planes in many cases aid the operations; while when the nitro-glycerine explosives are used it is easier to blast seamy rock than a solid, tough mass of rock. The volume of material loosened may be taken as approximately proportional to the cube of the line of least resistance, which is generally the shortest distance from the charge to the surface of the rock; the proportion, however, varies in different cases, but may be roughly estimated at twice that cube. "In ordinary blasts the proportion of the weight of the rock loosened to that of powder used ranges from 4500 to 1 to nearly 13,000 to 1, and is on an average about 6000 to 1 or 7000 to 1. The ratio of the number of pounds of powder to the cube of the number of feet in the line of least resistance ranges from 1 to 32 to 1 to 10."*

Road-stone quarries generally permit of a systematically planned method of working being carried out, and especially is this the case in blasting the rock, although the amount of the charge cannot be determined with mathematical exactness. An approximate calculation can be made, however, sufficient for all practical purposes, with a view to fix the quantity of explosive necessary to loosen a mass of rock by proceeding in the following manner, a system which the author has adopted and made use of for years past with satisfactory results. The cubic contents or burden of the rock surrounding each of the bore-holes is calculated in relation to the adjacent ones, allowance being made of about one-fourth the depth of the bore-hole beyond its position towards the solid and also below the bottom of the hole as the probable boundary line where the available effect of the explosive ceases.

To illustrate this, let fig. 73 represent a quarry face about 30 feet long with three bore-holes placed as shown, 14 feet deep; the probable lines of fracture or crater are shown by dotted lines. Shot-hole No. 1 is situated 11 feet from the face and 10 feet from No. 2, and the free end towards *a c* is shown as 5 feet; therefore the contents of the mass of rock *a b*, *d c* (taking 17 feet as the probable depth which will be affected), represents $(10 \times 14 \times 17) = 2380$ cubic feet, which, allowing 13 cubic feet in the solid to each ton of rock, amounts to about 183 tons. The contents or burden surrounding the other shot-holes are calculated in a similar manner. Should the shot-holes be fired singly, the line of rupture will not follow the dotted lines *a b*, *d c* but may be approximately represented at *e*, *f*, *g*, when the

* Rankine's *Civil Engineering*.

quantity of rock dislodged may only amount to about 120 tons. If blasting powder is used, and the shot-holes are fired singly, experience demonstrates that 1 lb. of this explosive can move from 3 to 4 tons of rock, and in the case referred to a total quantity of 30 lbs. would be required in order that the charge should be strong enough to overcome the resistance presented by the cohesion of the rock. This is on the assumption that the bore-hole

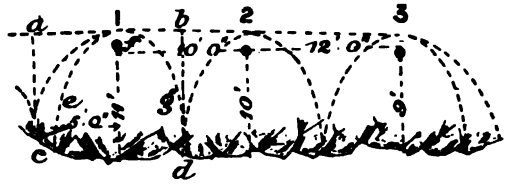


FIG. 73.

could contain this quantity of powder and admit of a sufficient amount of tamping being placed on the top, otherwise part of the charge would be blown out, diminishing its useful effect, and at the same time throwing the shattered rock at the mouth of the bore-hole in all directions.

In the event of the shot-holes Nos. 1, 2, and 3 being fired simultaneously by electricity, then 1 lb. of blasting powder will throw down from 5 to 6 tons of rock, hence in the case of No. 1 hole rather more than 36 lbs. will be required to dislodge the mass *a b*, *d c*, or 183 tons of rock.

It is evident, therefore, that simultaneous blasting, even when using blasting powder, gives better results than when the shot-holes are fired singly. In very hard and tough rock the effect of blasting with blasting powder as an explosive agent is such that the mass of rock is simply dislodged; the large size of the blocks of stone resulting necessitates an additional expenditure to reduce them sufficiently, by means of plug-holes, for the purpose of sledging. This work is performed by boring a hole $\frac{3}{4}$ of an inch in diameter in the block, and about 1 or 2 feet deep, inserting powder, tamping, and firing the charge, so that it may be split in several directions, and reduced to pieces of a suitable size for sledging. This on an average requires from 5 to 10 lbs. of powder extra for each 100 tons of rock, and the inclusive cost of this drilling operation may amount to 2d. per ton quarried. This extra work, in addition to the mashing or sledging, which is an item involving considerable expenditure, will be explained in detail further on.

On the other hand, if dynamite containing 75 per cent. of nitro-glycerine is employed as the explosive agent, the quantity necessary to dislodge and effectually shatter the same mass of rock, *e*, *f*, *g* (fig. 73), would, firing the shot singly, amount to 12 lbs. In the event of all the shot-holes being fired simultaneously, which is the only economical method, then the quantity of

dynamite necessary for shot-hole No. 1, allowing 13 to 14 tons of throw for each pound of explosive used, would be about 14 lbs. for the larger quantity of rock, namely, 183 tons.

In dimension-stone quarries, where the material is dislodged in large pieces, a considerable amount of work is entailed in reducing them by means of plug-holes and blasting. Formerly the plug-hole was usually made by hand-drilling, but the pneumatic hammer is now being introduced for this purpose. This tool, which is an adaptation of Boyer's patent hammer for caulking boilers and chipping purposes, can make a plug-hole 1 inch diameter and 12 inches deep in three minutes. Undoubtedly the pneumatic hammer has a great future, as, besides being capable of boring holes, it can be applied for dressing the hardest rocks, which has long been a desideratum in the granite industry.

The relative strength of the two blasting agents mentioned has been ascertained by the 'ballistic' test, and experience shows that in the generality of cases the figures given may be relied upon when blasting any mass of rock, provided the conditions as to drilling the bore-holes have been observed. It is necessary, however, to carefully inspect the fissures and characteristic features of the rock, as the position of the bore-hole in a mass of rock may be to a certain extent locked or keyed, under which circumstances an additional quantity of explosive may be advantageously used. Blasting gelatine, as already stated, is about nine times stronger than blasting powder; but we may assume it to be only eight times as strong, as this figure harmonizes best with the results obtained in practice. Consequently, in firing the shot-holes simultaneously by electricity, the quantity of this explosive necessary for charging bore-hole No. 1 (fig. 73) would be about 5 lbs. The effects of blasting gelatine, however, are slower in action than dynamite, so that the mass would be brought down in large blocks, necessitating plug-holes and the employment of additional explosive to reduce the stones to suitable dimensions.

Increasing the calculated quantity of blasting gelatine to, say, 8 or 9 lbs. would only have the effect of partially shattering the rock, while the mass would in all probability be thrown to a considerable distance, necessitating its being recovered and deposited at the quarry face. In extremely tight places in a quarry face blasting gelatine will burst and throw a mass of rock, while dynamite will only shatter it without dislodging it. The same process is carried out in determining the charges for the other shot-holes, and although it occupies some time and is only approximately accurate, it is nevertheless an infinitely better method than that usually adopted of fixing the amount of explosive necessary to discharge a mass of rock 'by sight.' The latter method of fixing the quantity of explosive required, or, as it proves to be in most cases, guessing, is a 'rule-of-thumb' system of arriving at the desired results, for, in such cases, it is usually found that the quantity

of explosive used was either too much or too little for the work to be done. Overcharging the shot-holes is a dangerous practice, and should be carefully guarded against in all quarrying operations.

197. The position and direction of the bore-holes in road-stone quarry No. 2, taken from actual practice, are shown in fig. 74, as also the quantity of explosive (dynamite) used and the depth of each shot-hole; for instance, in $\frac{10}{14}$ the lower figure indicates the depth of the bore-hole, the upper one the amount of charge in pounds, while the holes are indicated by the numerals 1, 2, 3, etc.

The quantity of explosive used in each shot-hole was determined by the method described; in the top holes 1 lb. of dynamite was allowed for dislodging 13 tons of rock, while in the bottom holes 1 lb. was allowed to

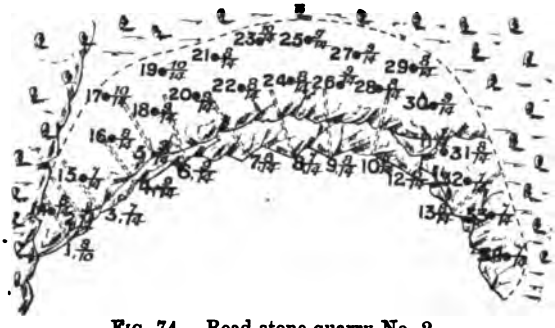


FIG. 74.—Road-stone quarry No. 2.

every 10 tons of rock. The total quantity of material calculated as likely to be dislodged was 3400; but the actual quantity of rock quarried and passed over the steelyard was 3475 tons, so that on an average 12¼ tons of rock was thrown or dislodged and broken up for each pound of explosive used. The appearance of the quarry face during drilling operations, and previous to blasting, is shown at fig. 88, while the result of the blasting, taken immediately after the shot-holes were fired, is represented in fig. 89.

198. Another example of a road-stone quarry, No. 3, is shown in fig. 75; the position and direction of the bore-holes, and the quantity of explosive used in each, are represented in a manner similar to that described in the preceding paragraph; a cross-section A A and the quarry face are shown in fig. 76. In this case the quarry, although in use for several years, had never been blasted, the limited quantity of metalling required each season having been obtained from the loose material on the top by means of bars and wedges.

The rock consists of basalt of a very tough and stubborn nature; consequently it was considered advisable to place the bore-holes closer to each other than in the cases referred to.

The amount of rock required for the purpose of forming a new road in the vicinity was 2000 tons, and considering the nature of the rock it was deemed advisable to work within a safe limit, the amount of the charge allowed being 1 lb. of explosive to every 10 tons of rock. The appearance of the quarry face previous to blasting is shown in fig. 90, and the result obtained is represented in fig. 91.

The actual quantity of rock dislodged and broken up suitable for sledging turned out, after weighing, to be 2102 tons, or equal to 10½ tons

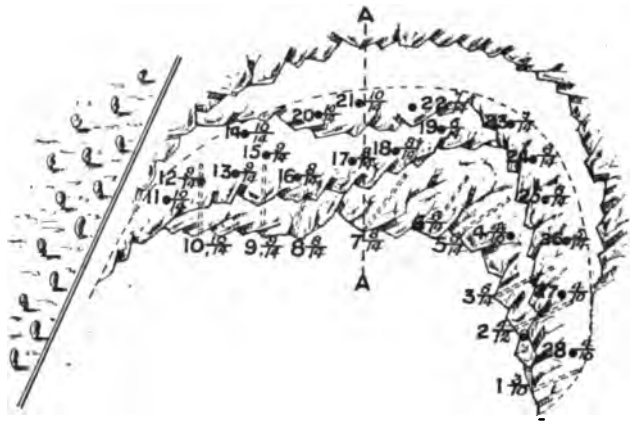


FIG. 75.—Road-stone quarry No. 3.

of throw for each pound of explosive used. The actual cost of drilling, charging, and blasting in these two quarries is given in detail on pp. 171 and 172.

199. Charging the Shot-holes.—Before commencing the operation of charging the shot-holes, it is necessary to remove any sludge or water which may be in them by the means already described, in order that they may be rendered as dry and clean as possible. Moisture will cool the gases produced from the explosive when fired, and therefore a part of the energy is uselessly expended in evaporating it, while the action of some explosives is lessened or prevented by it. If blasting powder in a loose state is to be employed as the explosive agent, particular care should be exercised, for the reasons given. The bore-holes ought to be thoroughly wiped dry by means of a piece of tow or other suitable material attached to the eye of the scraper, which is passed slowly up and down the bore-hole to absorb the moisture.

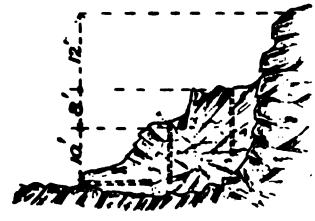


FIG. 76.—Cross-section at A A of road-stone quarry No. 3.

After determining the amount of the charge by the rule given, the requisite quantity is placed in the shot-hole; if the explosive is blasting powder in a loose state this is accomplished by means of a tin or copper tube, so as to prevent its coming in contact with the sides of the bore-hole. Blasting powder is also made up in cartridges having a waterproof covering, in which form it has many advantages. One pound of blasting powder in a loose state occupies about 30 cubic inches, and 27½ cubic inches when pressed, so that the quantity to be placed in a bore-hole can be determined exactly by measurement. Dynamite and the gelatinous explosives are made up in cartridges with paraffined paper wrappers, and are generally 3½ inches long and 1 inch in diameter for the former and ⅞ths of an inch for the latter. Boxes containing 50 lbs. are subdivided into ten cardboard boxes made up of 5 lbs. each. The number of sticks to a pound of the nitro-glycerine explosives can thus be easily ascertained, being generally 8 or 9, and this at once is a measure to guide the quarryman in charging the shot-holes.

The plastic nature of the nitro-compounds affords a great practical advantage in charging, as it admits of their being readily rammed home into the shot-hole, so as to fill all the seams and crevices. It is advisable, in order to save time when charging machine-drilled shot-holes, to place three sticks of explosive at a time into them instead of singly; this is done by tying them together with a piece of twine previous to commencing the charging operations, the combined thickness being sufficient to fill the lower part of a 14-foot bore-hole. They are then dropped into the vertical holes, and pushed into the horizontal ones, to the required number, and thoroughly rammed home, each lot of three separately, by means of a tamping rod made of wood, without using undue force; the more compact the cartridges are the greater will be the effect of the explosion.

If a charge of blasting powder is to be fired by means of a straw, a pointed metal rod of small diameter called a *pricker* is placed against the side of the bore-hole, with its lower or pointed end in the charge. The tamping is then proceeded with, which, considering the heaving tendency of blasting powder, requires not only that it should be firmly rammed, but also that the material forming the tamping itself should be of a dense nature, as, for instance, moist clay.

The pricker is then carefully withdrawn, leaving a circular passage through the tamping down to the charge. Into this passage the straw, properly filled with powder of fine grain, is inserted; the charge is then ready for firing.

This method of firing charges, although defective in many respects and attended with danger owing to the number of supposed misfires, was the method exclusively adopted years ago, but is now prohibited by the regulations of the Quarries Act, 1894.

The firing of a powder charge is generally effected by means of a safety fuse, a piece of which, sufficiently long to reach from the top of the charge

and to project a few inches above the bore-hole, is placed in a similar position to that occupied by the pricker in the case referred to, and the tamping proceeded with in a similar manner as described in the preceding paragraph. Better results will, however, be obtained if the fuse is placed in the centre of the charge so as to ensure its igniting and exploding properly.

It is a well-established fact that an electrical current will produce a more powerful initial impulse in firing shot-holes charged with powder than by the ordinary safety fuse; this method of blasting will be described presently.

In blasting with dynamite and the other nitro-compounds as the explosive, the firing cannot be effectively carried out by safety or any other kind of fuse alone. To bring about instantaneous decomposition in the nitro-glycerine class of explosives it is necessary to produce in their midst an explosion of some other substance. This is effected by means of a detonator, or copper capsule containing fulminate of mercury.

A short piece of safety fuse with a clean-cut end is inserted into the open end of the detonator till it reaches the fulminate; the detonator is then pressed tightly round the fuse by the aid of a pair of pliers specially made for the purpose. The detonator is then pushed to a depth equal to two-thirds of its length into the primer, a hole being previously made in the primer by means of a small round piece of wood having a similar diameter to that of the cap or detonator, the paraffined paper wrapper is then laid over and secured to the fuse. To ensure proper detonation the safety fuse in the cap ought not to touch the dynamite primer, as, should this occur, the explosive may become ignited previous to the fulminate of mercury in the cap exploding, which, besides creating noxious fumes, would detract from its explosive effect. The method of fixing the fuse and the other details necessary are shown in fig. 77, *a* being the fuse, *b* the detonator, *c* the primer or cartridge of dynamite, and *d* where the paraffined paper wrapper is secured to the fuse by a piece of twine.

FIG. 77.—Dynamite primer and ordinary fuse.

When damp or wet bore-holes are encountered, it is advisable to smear the connection between the detonator and the fuse with tallow or some other kind of water-resisting composition.

It is a common practice to insert a paper wad on the top of the primer and detonator before the tamping is commenced; this forms a cushion and protects the detonator.

When a number of shot-holes are to be blasted simultaneously, the employment of electricity to fire the charge presents numerous and great advantages; even in single-shot firing it is much superior to the safety fuse and detonator by its producing a greater useful effect.

200. Electrical Detonators.—These consist of a charge of explosive compound, usually fulminate of mercury, suitably placed in the circuit of an

electric current, and acted upon in a manner and degree sufficient to produce an explosion. The mode in which the current of electricity is made to act depends on the source or manner in which it is generated, being either of high intensity but small in quantity, or of low tension and of great quantity.

Two kinds of electrical exploders are therefore manufactured, consisting of three types to suit these two different conditions or sources from which the electric current is produced. These three types are the *slot* detonator, fig. 78, the *bridge* detonator, fig. 79, and the *incandescent* detonator, fig. 80, but are commonly called tension and quantity detonators.

Slot Detonator.—The slot detonators are thin copper tubes—*a*, about ¼ inch in diameter, closed at one end and partially filled with a detonating composition, *b*, consisting of fulminate of mercury in varying quantities up to 2 grammes or 31 grains. On the top of this composition there is placed a layer of priming or flashing mixture, *c*, which is generally made of antimony sulphide and potassium chlorate. The wire for conveying the electric current is bent at the lower end in the form of the letter U, around which a plug, *e*, of melted sulphur and powdered glass is moulded, a fine slot being cut through the wire as shown at *d*. The plug is then inserted into the copper casing, so that the two bent ends of the wire project into the priming mixture; it is then made water-tight with india-rubber solution.

Bridge Detonator.—The bridge detonator is similar in form to the previous one; the wire terminals are, however, filed off flush with the inside face of the plug, along which and between the ends of the two wires a line

Slot. Bridge. Incandescent Detonator.

FIGS. 78–80.—Electric Fuses.

is drawn with a soft black lead pencil. This forms a path for the electric current to pass along, with many points at which sparking takes place.

Incandescent Detonators.—The incandescent detonators are made in a similar manner to the slot type, but the ends of the wires are placed in the priming or flashing mixture and connected by a very fine platinum wire, *d*.

Owing to the great electrical resistance of the platinum wire, it becomes red hot when a current is passed, thereby effecting the necessary explosion.

This type of exploder requires an electrical current of great quantity to explode it, but of low tension, while the slot type of detonator requires a high tension current to ignite it. Detonators contain a mixture of from 80 to 95 per cent. of fulminate of mercury and 20 to 5 per cent. of chlorate of potash, those for electric blasting generally containing 90 to 95 per cent. of the former and 10 to 5 per cent. of the latter. They are manufactured with charges varying from 8 to 31 grains; No. 6 detonator, or sextuple strength, containing 1 gramme or 15·4 grains, are those usually employed in quarry work for supplying macadam. Detonators of insufficient strength are a source of danger, and many accidents are traceable to explosives of the nitro-compound class being improperly exploded. It is essential, therefore, to employ those of a proper strength to ensure effective work; in many cases No. 8 detonators are employed, especially in very wet bore-holes; these contain a charge of 31 grains. The lowest standard for detonators required by the Home Office is 80 per cent. fulminate of mercury and 20 per cent. of chlorate of potash.

201. The detonators are inserted in the primers, whatever kind of nitro-compound explosive is used, by making a hole at one end by means of a small piece of round stick, thoroughly covering the exploder with the dynamite and securing the paper wrapper to the wires by means of a piece of twine.

It is then placed in the bore-hole and in contact with the charge, the wires being sufficiently long to reach at least a foot beyond the surface of the rock.

202. Some authorities on blasting claim, in order to properly fire a charge of dynamite or the gelatinous compounds, that the detonator should be placed in the centre of the charge, and that even two or three should be employed and distributed in the body of the charge to obtain, if possible, a higher initial explosion. This, no doubt, would have a beneficial effect in extremely deep shot-holes, and where the charge is an extended one of great length; but to properly charge and tamp a hole under such conditions is a matter of great difficulty, and the process is not wholly free from danger. It is desirable, however, when blasting rock which is likely to be dislodged in large blocks, to divide the charge; that is, first placing one-half the calculated quantity of explosive in the lower part of a bore-hole to fix the detonator in position, tamping material being added to a height of a few feet, then placing the remainder of the charge on the top of this, and repeating the process of fixing the detonator and tamping. Care should be taken, when working with double charges, to properly join the shot-hole wires to those on either side.

203. Tamping the Shot-hole.—The effective tamping of the shot-hole after the charge has been inserted is a matter of great importance, as the object

is so to increase the resistance as to prevent the escape of the gases generated by the explosion in the direction of the bore-hole. The material employed must therefore possess great power of resistance, be of easy application, and be free from grit or other hard matter which would have a tendency to cut or damage the insulation of the wires in the shot-hole. Moist clay suits the first condition admirably, but its application in tamping the bore-hole occupies a considerable time. Sand satisfies the second condition, but even when compact, water permits of the gases being insinuated between its particles.

When blasting powder is used, a sufficiently deep and solid tamping is indispensable, and no time should be spared to make it thoroughly uniform and tight. The action of blasting powder when exploded has a lifting tendency; it should, therefore, be tamped entirely with clay in order that the full explosive effect may be directed on the rock to be dislodged.

When a charge is fired by detonation, the action being much quicker than with safety fuse, the tendency just mentioned is greatly diminished.

With the nitro-glycerine class of explosives sand alone is often used; the general effects of the blast, however, are considerably increased by employing a few pellets of clay in addition. With a powder charge it is usual to place a wad of paper or straw next the explosive before commencing tamping operations, and then slightly press the material until a safe height above the charge is attained, when it may be rammed. In tamping a dynamite charge it is usual to place some sand in the shot-hole directly on the detonator so as to cover it; a few pellets of moist clay are then gently pushed over this for a foot or two in depth, when the ordinary tamping material is scooped into the shot-hole and rammed with a wooden rod until the surface is reached. Care should be exercised to avoid a cushion of air between the explosive and the tamping material.

In either case the man who is deputed to do this work should hold the fuse or the wires of the electric exploder in his left hand while he works the tamping-rod with the other hand. The least movement of the fuse or wires caused by the tamping-rod coming in contact with them will be instantly felt; this enables the operator to avoid the rubbing, which is injurious to them. Apart from the possibility of cutting or destroying the covering or insulation, which in damp shot-holes might adversely affect the firing of them, the wires of the electrical exploders may be broken by incautious handling and thus rendered inoperative. For this reason the tamping-rod is sometimes made with a slanting instead of a square end, as shown in fig. 81. It will be seen that the point *a* will always have a tendency to rub hard on the rock face of the bore-hole farthest away from the fuse or wires, thus guarding against the least possible chance of damaging them. After the tamping-rod is placed in the bore-hole, however, it may be uncertain at which side the point *a* is situated. To obviate this difficulty it is advisable to run a groove diametrically opposite to the point *a* the whole

length of the rod, then by observation it can be held in the position which will keep the point as clear of the fuse or wires as possible.

Tamping shot-holes charged with the nitro-compounds by means of water has many advocates and is extensively made use of, but in the author's experience such a method of tamping has not been attended with satisfactory results, and is certainly not to be compared in any way with the system of tamping described in the preceding paragraphs.

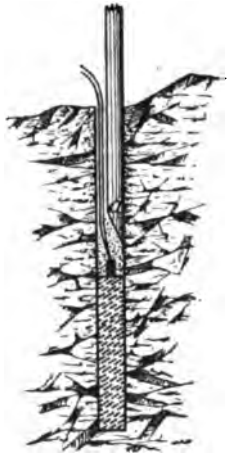


FIG. 81.—Tamping rod.

204. Nature of an Explosion of Nitro-Compounds.—It is generally believed, even by those of some experience, that the direction of impact of the nitro-compounds, when exploded, acts in a downward direction. This is not the case, however, as may be inferred by considering the following facts, which do not justify the general use of water as a means for tamping shot-holes.

If a cartridge of dynamite is suspended in mid-air, where the resistance around it is equal on all sides, it will, provided the explosive is of a uniform composition, and is detonated throughout its body simultaneously, cause the gases generated to expand equally in all directions. The only difference between the explosion of a charge of blasting powder and that of a dynamite cartridge is one of degree, the latter being much more quickly converted into a gaseous state; hence its action is rapid. If a cartridge of blasting gelatine or dynamite be placed on a block of stone and detonated, it is possible that under most circumstances the stone will be cracked in several directions. This does not prove, however, that the impact is entirely downwards, as only a limited amount of the explosive effect created may have acted in this direction by reason of its rapid action on the surface of the stone. A cartridge of the same kind and strength placed in the bore-hole of a block of stone of equal size and solidity and effectively tamped—in other words, similar to the one already operated upon—having equal resistance all round, would cause it to be shattered and the fragments would probably be thrown in all directions. It will thus be seen that, with an equal resistance, the gases generated by the explosion of dynamite will expand equally in every direction. Should the resistance be unequal, however, the explosive effect will be deflected in the direction of the line of least resistance. Hence in shot-holes tamped with water it sometimes happens that the deflected energy of the explosive follows the bore-hole, as it easily overcomes the resistance of the water, and expends its useful effect in the air. This explanation of the nature of an explosion of the nitro-compounds is amply borne out in practice. In carrying out some quarrying operations the

author had occasion to make use of water tamping, not as a matter of expediency, but from necessity. Of twelve shot-holes which were fired simultaneously three simply discharged the explosive into the air and on the quarry face opposite, the result being devoid of any useful effect. Two of these bore-holes were in a horizontal position and one vertical; from the last mentioned a small piece of loose rock surrounding the mouth of the hole was projected to a considerable height, and subsequently fell within a few feet of its previous position in the quarry. In bore-holes generally (especially in those drilled in a vertical direction) when there is a continuous flow of water (as was the condition of things in the case mentioned), it is advisable to place a few pellets of clay over the charge and to fill the remaining portion of the hole with sand. This assists in confining the gases when expanding, and therefore increases the effective results. Similarly, if the full force of an explosion is deflected when an accidental explosion of the nitro-compounds takes place, distant objects may be damaged, while objects comparatively near in different directions may not be affected.

205. Connecting the Shot-hole Wires.—When two or more shot-holes are to be exploded simultaneously, the wires leading from the detonators require to be joined to those on either side and also to the cables leading to the blasting machine, so as to form a complete metallic circuit. When the wires from the shot-holes are not long enough to join those on either side, it is necessary to make use of connecting wire, which should be of the same quality as the detonator wires and of a similar diameter. These latter are made from $\frac{1}{64}$th to $\frac{1}{32}$nd of an inch in diameter, and are insulated with paraffined cotton wound double, or with gutta-percha or fibre composition. The mode of joining the wires is to cut off the insulated covering for about 3 inches from the end of each wire, and then twist them together firmly in a somewhat reverse fashion, as shown in fig. 82.

The bare ends should be scraped with a knife, as the contact surfaces must be clean, bright, and free from dirt or grease. These bare con-

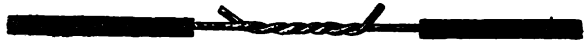


FIG. 82.—Method of connecting wires.

nections when the ground is wet should be protected by covering them with insulating tape; this is especially necessary when the explosion of the charge is effected by a blasting machine generating a high tension current.

206. Circuits: different methods of connecting-up.—In effecting the metallic circuit between the shot-holes and the end of the cable wires, three different systems may be adopted in coupling-up the detonators, viz., (1) in series, (2) in parallel, or (3) in a manner combining both systems.

(1.) *Series Circuit.*—The method known as the *series* circuit, or connecting the wires in series, and shown in fig. 83, is the one most frequently adopted when low tension or quantity detonators are used, which arrangement can be tested previous to firing. It affords a simple and effective means of forming the connections. Its only disadvantage is that a single defective

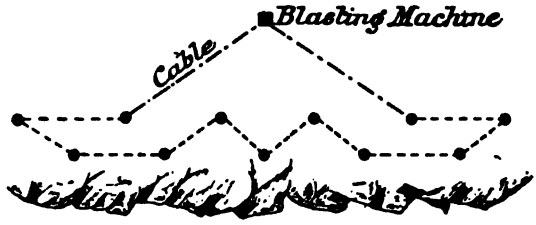


FIG. 83.—Connecting the shot-hole in series.

detonator or faulty shot-hole wire will prevent all the others being fired, and cause what is termed a *misfire*; but by testing the exploders previous to inserting them in the shot-hole the risk of the defect mentioned may be reduced to a minimum.

(2.) *Parallel Circuit.*—The mode of connecting the wires in parallel or direct circuit is shown in fig. 84; the wires of each shot-hole are in direct communication with the cables, and as they are independent of each other, they are free from the disadvantage incidental to the series method of forming the connections. The great amount of wire necessary to form the connection by this system, especially when there are a considerable number of shot-holes to be fired, increases the cost of the operations considerably.

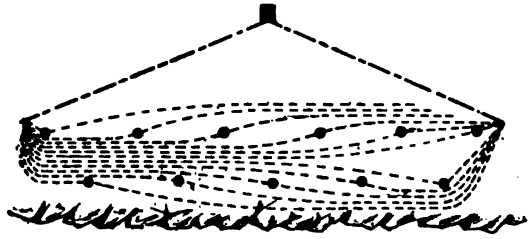


FIG. 84.—Connecting the shot-holes in parallel.

The connecting wires, instead of being placed so as to take the circuitous direction indicated in fig. 84, may be arranged in straight line between the shot-holes and the ends of the cable wire. They must, however, be kept entirely separate from each other in order to avoid complications, and the bare parts must be properly protected to ensure perfect insulation.

(3.) *Series and Parallel Circuit.*—The other method which may be adopted is a combination of the series and parallel circuits; this arrange-

ment is shown at fig. 85. It will be observed that should a defective detonator exist in the front row of shot-holes *a b*, none of the others in that row can be fired; consequently, the back row of shot-holes, if they are

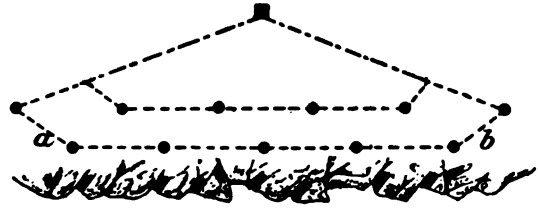


FIG. 85.—Connecting the shot-holes in series and parallel.

in order, will be exploded. The force exerted, however, will not be sufficient to dislodge the rock in front, which, had the charges in all the shot-holes been exploded simultaneously, would have been effected.

207. Connecting to Cables and Terminals of the Blasting Machine.—A wire from each of the detonators in the shot-holes nearest to the blasting machine is connected to the ends of the cable; and the other wire, as already explained, is connected to the next shot-hole wire when in series, and to the other cable when the parallel circuit is adopted.

The double cable is preferable for open quarry blasting; when high-tension detonators are employed the material of which the wires are composed is of little importance; it may be of iron. For low-tension detonators the leading wires or cables are made of copper, and of a comparatively large section, so as to admit of as small a line resistance to the current as possible. They are protected by gutta-percha or other suitable insulating composition, and for convenience in using and storing should be wound on a reel. This is a matter of some importance, as, when a cable is used without such an accessory, the time lost and the trouble occasioned by the wires becoming a tangled mass is very great, and result in the insulation being destroyed, and possible damage to the wires. As the blasting depends on a thoroughly efficient metallic circuit it is necessary, before using the cables in actual work, to test this by attaching them to the blasting machine and holding the free ends together, when, if they are in good order, a spark will appear on the current being sent through the cable wires.

208. Firing or Blasting Machines.—Machines for exploding the detonators, and consequently detonating the charge in the bore-hole, are, as may be inferred, of two kinds. The blasting machine for firing tension detonators must be capable of producing a high tension or voltage, this being necessary to decompose the priming compound contained in the cap or detonator. The chief advantage of this class of blasting machine is the small effect of line resistance upon the current, in consequence of which the charges in the shot-holes may be situated at a relatively great distance from

the blasting machine. As there is no possibility of testing high tension detonators except in actual blasting, it is usual to connect or couple up the shot-holes in parallel, so that each may be independent of the other; this minimises the trouble which may be experienced from a misfire should a faulty detonator happen to be in the circuit.

All the wires connecting the blasting machine and the detonators in the shot-holes must be perfectly insulated, however, as the smallest leakage of the electric current will greatly reduce the useful effect in blasting, and possibly lead to total failure. The high tension type of blasting machine is much employed in mines, and in single-shot firing; those principally used in this country are known as the 'Rackbar Exploder' (Smith's), and the 'Siemens' Exploder.' The Rackbar blasting machine, weighing 42 lbs., is capable of exploding simultaneously twenty-six high tension detonators in parallel. The Siemens' Exploder can only be used for firing high tension detonators, and is made of different sizes. The smallest size, 100 volts, weighs 8¼ lbs., and can fire sixteen detonators, while the largest size, having four times that voltage, and weighing 21 lbs., can fire twenty-five high tension detonators.

For general quarry operations, however, the low tension system of blasting is in most favour, and possesses many points of great superiority compared with that of high tension 'exploders.' Low tension detonators possess the advantage that they can be tested, previous to being inserted in the shot-hole, by means of an electric galvanometer or by an electric fuse and blast tester. There is also the additional advantage that the whole charge can be tested by a weak current of electricity before connecting the leading wires to the blasting machine.

This testing machine is of great convenience, for, although detonators are now manufactured with great care, and seldom cause a misfire when proper care is exercised in handling them, still a detonator-testing machine is a valuable accessory to a blasting outfit, and its use may save considerable trouble and expense.

It is not of great importance that the wires for blasting on the low tension system should be thoroughly insulated, as bare wires are often used; but in damp places it is advisable to employ insulated wire, and to cover the joints or places where the connecting wires are coupled-up to avoid any possible escape of the electricity. The line resistance in connection with blasting machines generating a low tension current necessitates the employment of copper wire (as already mentioned) for the cables, which need not be of great length for ordinary quarry work. The length of the leading and connecting wires has a considerable influence on the total resistance in the circuit, consequently as this becomes greater the number of shot-holes which can be fired effectively will become less.

It is therefore usual to connect the shot-hole wires in series, because, as the detonators can be tested prior to the blasting taking place, there is but a

small chance of a misfire. When the means of testing the detonators are not at hand the wires may be coupled-up in parallel, but of course a less number of shot-holes can then be fired simultaneously.

209. The principal blasting machines for firing low tension detonators used in this country are 'Siemens' Exploder,' 'Rackbar Exploder' (Smith's Blasting Machine), 'Crescent,' and 'Victor.'

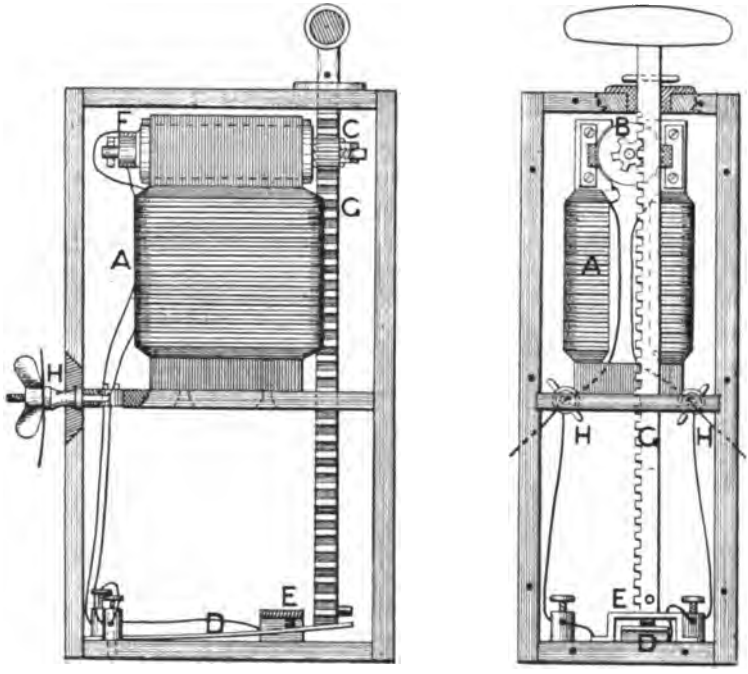
The Rackbar exploder or Smith's blasting machine, already mentioned, is extensively used in this country. It is a very serviceable machine, the largest size being capable of firing twenty-six high tension or thirty-five low tension detonators; it is of simple construction, and very effective when properly manipulated. The Crescent blasting machine is of strong construction, and although of considerable weight it is a very effective machine, being capable of firing thirty-five shot-holes simultaneously. This is the only electric blasting machine, so far as the author is aware, which discharges a uniform current of electricity on every occasion, no matter who may operate it. To obtain the best possible results with the other machines mentioned the operator must have had some previous experience, as it is possible to give a weak or a strong current at will, or by improper manipulation. Even those experienced have difficulty at times in operating these machines so as to discharge exactly the same quantity of current at each operation.

210. Figs. 86, 87 illustrate the interior construction of a Smith's or Rackbar blasting machine, which, for effective working, compares favourably with any of the others, while the small size and moderate weight are greatly in its favour.

They all depend on the manner in which the electric current is generated, which is practically the same as in a dynamo.

The iron magnet A is of the horse-shoe type, wound about with coils of insulated copper wire, and between the poles of the magnet there is a revolving cylindrical armature B, on the body of which insulated wire is coiled longitudinally. The rapid revolution of the armature generates and sustains in the machine an accumulative current of electricity of great power, which at the moment of its maximum intensity is switched off to the outside circuit, in which are the detonators. C is a loose pinion, its teeth engaging with the rackbar G, and, by a clutch, engaging with the spindle of the armature in the downward stroke of the rackbar. D is a spring which, when struck by the foot of the descending rackbar, breaks the contact between two small platinum bearings E, and causes the whole current of electricity to pass through the outside circuit. F is the commutator, while at H are shown the binding-posts or screws, to which the cables are attached. These machines are sometimes made with three wire connections, namely, two out-current wires and one in-current or return cable. It is claimed that more effective work is performed by machines possessing this arrangement, but as yet few of them are in actual use.

211. Final Arrangements for Blasting.—The final arrangement necessary to be made in carrying out the blasting is to place the machine at a safe distance from the quarry face, so that the operator and the machine itself will be out of reach of any pieces of rock which may accidentally be projected from the shot-holes when the charges are exploded. In most cases 100 to 150 yards is a safe distance, and provided the bore-holes are deep and the tamping is properly executed, there is little chance of any mishap occurring at this distance. In blasting, the rock operated on falls or is thrown in the direction of the least resistance, that is, from the rock mass



FIGS. 86, 87.—Sections of Smith's blasting machine.

towards the open portion of the quarry. The blasting machine, therefore, should be placed in a position opposite in direction to that in which a rock mass is expected to fall, so as to ensure its being placed in the least exposed situation. It is always necessary to bear in mind that from some cause or other a few detached pieces of rock may be projected upwards in an inclined direction; therefore, when consistent with the preceding observations, it is advisable to locate the position of the blasting machine so that the operator's view of the quarry will not be interrupted by the sun's rays.

The cables are then connected to the binding-posts or thumb-screws of the blasting machine, the workmen are ordered to retire to a place of safety,

everything is made ready, and the customary signals are exchanged. The handle or rackbar is then put in operation, and the requisite electrical current generated, which is switched off into the circuit, when, if everything is in proper order, a simultaneous explosion will be the result, accompanied by a low rumbling noise which indicates effective work.

212. As a substitute for electrical firing, friction fuses have been employed at times, and also instantaneous fuses; the latter are still much used in some of the large quarries in England and Wales.

213. The instantaneous fuses or volley-firers made by the firm of Beckford, Smith & Co., of Tuckingmill, which are claimed to act simultaneously, differ from this firm's ordinary safety fuse in having a core of cotton wick which has been drawn through a paste of meal powder, instead of a powder train. When it is desired to fire several shots by means of this fuse, the required number are inserted into a tin socket or volley-firer, at one end of which is a plug of wood perforated to receive the time-fuse for igniting the instantaneous fuses leading to the shot-holes, and all the shot-hole fuses are concentrated in the receptacle and brought into contact with the disc. A gunpowder disc is placed against the plug, the whole being insulated with gutta-percha. The instantaneous fuse burns at the rate of 50 yards per second, and for open quarry work the T-pattern of volley-firer is generally made use of when the fuse is of any length.

These fuses have to be specially made when the number of the shots and the distance apart is great, which particulars must be ascertained some time previous to the blast taking place. As a matter of convenience, they are generally made up and connected by the makers at their works.

This method of firing may be approximately simultaneous for a few shot-holes, but when a large number are intended to be ignited at once, the varying lengths of the patent fuse must necessarily mean a difference of time, and although to all appearance the explosion is simultaneous, it is evident that a few seconds must elapse between the actual explosion of several of the charges. With electrical firing this is not so, as the current must pass from the blasting machine through the outer circuit and return to it again before all the detonators can be exploded. For quarrying in mines and tunnels Beckford's patent fuse, when a limited number of shot-holes are to be fired, may be adopted with great advantage.

214. **Misfires.**—Should a misfire occur, which unfortunately happens sometimes in practice, it may be traced to various causes, such as (1) a defective detonator, (2) faulty shot-hole wires, brought about by careless handling, (3) the weakness of the current generated by the blasting machine. The first two causes should not occur in low tension blasting, as they are discoverable by testing previous to firing. The best way of guarding against the third cause is not to have more shot-holes than the machine will fire with certainty.

The manner in which a misfired shot-hole may be relieved, an operation not wholly free from danger, is to remove a small quantity of the tamping, insert another one or two detonators, re-tamp with clay, and fire in the ordinary manner. The vibration or detonation of the newly inserted detonators gives rise to a sharp shock, which may, and does at times, cause the charge to explode.

Should this means fail, and should it be absolutely necessary to explode the charge, then the tamping must be extracted, a process requiring great caution, perseverance, and time. When the tamping forming the cushion on the top of the explosive is reached, another detonator is inserted and the shot-hole re-tamped; on the charge being connected, it will in all probability be exploded. Another method of attaining the same object is to drill another bore-hole a few feet distant from the misfired one, and to a depth which will nearly reach the level of the top of the explosive in the hole which has failed to go off. This new bore-hole is then charged and fired, the loose rock carefully removed until the charge in the misfired shot-hole is reached, when by inserting another detonator and connecting the wires to the blasting machine, the charge can be fired.

When a bore-hole charged with blasting powder fails to explode, the cause may be traced to some inherent defect in the fuse itself, or to its having been damaged during tamping operations. The only means of rectifying this is to remove the tamping material, and to apply another piece of fuse, whereby the ignition and explosion of the charge will in all probability be effected.

215. Recording Charging Operations.—It is obviously most essential in quarrying operations, to record reliable data respecting the charging of the bore-holes. The depth from the surface of the rock to the top of the explosive in any particular bore-hole being known, the preceding operations in connection with a misfired shot-hole are possible, but when such information is wanting, it adds considerably to the difficulty, and may be the means of introducing an unnecessary element of danger during the operations.

216. General Deductions.—The following observations will indicate the superior economy and safety of machine-drilling combined with electrically fired high-grade explosives over the old method of blasting powder ignited by safety fuses, which is still used in some quarrying operations.

Deep holes tend to economy in drilling, if properly placed as regards position and direction, while the charges of the explosives when determined according to the proportion of rock to be dislodged, ensure useful work being accomplished.

The method usually followed of simply guessing what amount of explosive should be used to loosen a piece of rock, is wasteful in most cases, while the results obtained are variable and generally unsatisfactory. It may happen that an insufficient charge is made use of, dislodging the mass of

rock in large blocks; this necessitates a considerable amount of additional labour, in order that they may be reduced to a proper size. On the other hand, an excessive amount of explosive may be placed in the shot-hole, which will reduce the mass of rock to such a size as to entail considerable loss, owing to its being unnecessarily shattered. Another result of over-charging, and which happens in the majority of such cases, is brought about by the gases expanding, and (owing to the small resistance offered) throwing the shattered rock in all directions, even beyond the limits of the quarry. This necessitates its being collected and removed, and adds to the cost of the operations. It will be obvious from these observations that in order to properly estimate the amount of explosive necessary for dislodging a mass of rock it is essential to observe the directions of the fissures and determine the approximate charge from actual measurement of the cubical contents of the mass of rock to be dislodged. The methodical procedure of the experienced blaster always conduces to economy.

The simultaneous firing of the shot-holes reduces the total amount of work necessary, a less number being required; and, as compared with single-shot firing, there is a corresponding reduction in the quantity of explosive for a given quantity of rock to be dislodged, which means a great saving of expense.

Vertical holes should always be put down when possible, as the amount of explosive necessary to break up the rock into suitable pieces is considerably less for vertical than for bottom or breast bore-holes. When a quarry face is of considerable height, it will be more economical to work it in benches or terraces, varying from 15 to 20 feet deep and 12 to 16 feet wide, and by drilling vertical bore-holes.

There is no such a thing as 'hanging fire' when an electrical current is used as a means for firing the charges. If the shot-holes do not go off when the blasting machine is operated, the men can at once approach the quarry face with absolute safety, the only precaution necessary to be observed being to disconnect one of the cable wires in certain blasting machines, or to remove the handle, which should be retained by the operator. This precaution, during the temporary absence of the man in charge, prevents the machine being tampered with and a possible accident, which is, however, a very remote contingency.

With safety fuse it is otherwise, as almost all the accidents in connection with such blasting operations are brought about by their proving defective in some way or other. This fault may cause the fuse to 'hang fire,' and the workmen, probably after waiting for ten or fifteen minutes, approach the quarry face, when without warning, as has happened times without number, the charge explodes and the result may terminate fatally for those in close proximity. It requires but little reflection to understand that blasting by means of electricity is highly conducive to the safety of the men employed,

which is a feature in itself sufficiently important to make its application universal. When a large number of shot-holes are fired with safety fuse, and the contingency of misfires almost inseparable from this method of blasting is considered, it will be obvious that an excessive amount of time is lost each day. In quarries from which large quantities of material are turned out, the time thus lost would be entirely obviated by electrically blasting the rock.

The method by which the bore-holes are drilled, the shot-holes charged and tamped, and the blasting carried out, having been fully described, it now remains, so far as these operations are concerned, to ascertain what the cost of quarrying amounts to per ton of rock dislodged. The tirring or stripping may vary considerably, and the price for this work per ton of rock quarried will depend on the height of the quarry face in relation to that of the depth of tirr or overburden removed.

217. Cost of Working Rock Drills.—The author has found from experience, taking the work performed by a rock drill when boring from 35 to 42 feet of 2½-inch holes each day, that the rock after blasting and weighing averages from 250 to 300 tons. In other words, each 14-foot bore-hole, when blasted, produces about 100 tons of rock. From these data it can be easily ascertained what the cost of drilling amounts to, and from that the price per ton of rock quarried may be deduced.

Tirring or stripping may be taken at 0·68d. per ton of rock quarried.

TABLE XX.

Cost of working rock drill per day of nine hours.

Engine or boiler for generating steam, and attendant (hired), 11s.; coals, 6 cwt. at 12s. per ton = 3s. 7d., .	£0	14	7
Drill-runner, 4s. 2d.; assistant, 3s. 6d., ...	0	7	8
Dressing and tempering drill-bits, 4d. to 6d., according to their condition, each drill-bit boring on an average 4 feet before it requires to be dressed, ...	0	4	5
Oil and waste for drill only, ...	0	0	3
Team work, carting coals and water for engine, and the drill-bits to and from the smithy, proportion of day's work, ...	0	7	0
Repairs, depreciation, and tools, allow	0	0	6
Total, . .	£1	14	5

Taking the amount of rock produced, after blasting, as 250 tons for each day's work, it will be found that the drilling operations cost 1·65d. per ton. If the quantity be taken at 300 tons for a day's work, then the cost for drilling will be 1·38d. per ton. Each foot of bore-hole drilled,

taking 35 feet as a day's work and the working expenses as above stated, is found to be 11·80d. or nearly one shilling; while if 42 feet per day is taken it equals 9·83d. per foot of hole of the diameter stated.

In quarries where drilling operations are carried on nearly every day during the year, the cost of providing the motive power may be considerably reduced. The team work is dispensed with when the supply of water is conveniently near, while the proximity of a smithy further tends to reduce working expenses; but these items of expenditure are inseparable from the operations carried on under the conditions mentioned in the preceding paragraphs.

A smith who has some experience in dressing and tempering drill-bits will perform the work more expeditiously, and the results will be better than where the work is done by one only occasionally employed in this class of work. The price for dressing a drill-bit under the circumstances mentioned need not exceed 4d. each, provided they are only moderately dulled, but it may be 6d. if the drill-bit requires more labour to bring it into proper shape.

The cost of explosives varies according to the class made use of, but taking dynamite containing 75 per cent. of nitro-glycerine as that used in charging the bore-holes, the price, when obtained in small quantities for blasting one quarry, and where it is intended to dislodge about 1000 tons of rock, may cost as much as 1s. 3d. per lb.

218. The conveying of the explosive from some local magazine to the quarry where it is to be used, and thawing it when frozen, will increase the price by at least one penny before it can be placed in the bore-hole, and bring the total cost to 1s. 4d. per lb.

Dynamite, and indeed all explosives, when purchased in large quantities of say 1000 lbs. and upwards, can be obtained at a considerably less cost, in some cases to the extent of 35 per cent. Economy and convenience will therefore be secured by having a suitable store or stores situated centrally in the district, from which the different quarries can be supplied. A description and drawings of a mixed store for this purpose will be found at the end of this chapter. By having a store for keeping the explosives required the dynamite of the grade mentioned can be purchased, when taken in large quantities, for about 9½d. per lb. delivered at the store. When the building is situated centrally the cost of conveying the explosive is reduced considerably in the majority of cases, and an allowance of one halfpenny per lb. will cover the outlay for this, and also for the time occupied in thawing the explosive, should it be frozen.

219. One pound of this grade of dynamite, as has already been pointed out, will throw and break up 14 tons of rock when the shot-holes are fired simultaneously by electricity, but allowing 12 tons of rock to each pound

of explosive used, the cost will thus be 0·84d. for each ton of rock dislodged.

220. The cost of the electric platinum detonators, containing a charge of about 15 grains and having shot-hole wires 10 feet long, including connecting wire (which can be used again if not destroyed during the blasting operations), may be taken at 2d. for each shot-hole, or 0·02d. per ton of rock dislodged. The time occupied in charging the shot-holes, fixing the detonators in the primers, tamping, and connecting the shot-hole wires, varies considerably. If the bore-holes are in solid rock, little trouble will be experienced in carrying out these different operations; in seamy rock, however, the time necessary to carefully and properly perform the charging and tamping will be greatly increased. Taking an average, experience shows that the whole operation occupies four men (two pumping out the bore-holes and conveying the explosive to the other two men charging) one hour for every 40 lbs. of explosive stemmed in the bore-hole, ready for blasting, including all the other necessary work involved. Five shot-holes can, on an average, be completed in an hour; so that, allowing for coupling-up the connecting wires and cables, an inclusive sum of 4½d. to 5d. may be taken as representing the cost for this work for each bore-hole. This is equal to 0·06d. per ton of rock.

221. **Sledging the Rock for Hand or Machine Breaking.**—The last operation consists of mashing or sledging the larger pieces of rock small enough to suit the hand-breakers for producing road metal or for a breaking machine, the general size being about 16 inches by 9 inches. The price per ton for this work depends upon the ease with which the rock can be broken. The quantity of rock of a siliceous nature which one man can sledge in a day of nine hours, including a large proportion of rock already small enough, is on an average about 20 tons; so that the cost would be 2½d. per ton quarried. Should the rock be of a very tough nature, and especially if it is in large blocks, the yield per day may only amount to 12 tons. An average of these quantities, namely, 16 tons, fairly represents an ordinary day's work by one man. When vertical bore-holes alone are drilled, the cost of sledging is materially reduced, by reason of the mass of rock falling to the quarry floor being broken into smaller blocks.

The cost of sledging, therefore, allowing 3s. 8d. per day for each man engaged in this work, and including an allowance for tools and repairs, amounts to 2·75d. per ton.

222. All the items summarized for the different operations involved in quarrying the rock to a size suitable for a 16 inches by 9 inches stone-breaking machine are as follows:—

TABLE XXI.

Cost of quarrying rock per ton, including mashing or sledging.

	Pence per ton.
Tirring or stripping,	0·68
Drilling, including repairs and depreciation,	1·65
Explosives,	0·84
Detonators and connecting wire,	0·02
Time occupied in charging the shot-holes, fixing the detonators, tamping, connecting the shot-hole wires, arranging the cables, etc.,	0·06
Mashing or sledging,	2·75
Cost per ton,	6·00

From this summary it is apparent that the cost of sledging is relatively high compared with that of explosives. The great object to be attained is the use of just a sufficient amount of explosive so as to save after manipulation, but at the same time overcharging the bore-holes should be avoided, which, besides scattering the rock about, reduce it in many instances to a size too small for the purpose intended.

In quarries where 'sets' of stone-breaking machines are used it is usual to have one at least of these, generally known as a reducing machine, working in connection with two or more ordinary macadam breakers. Under these conditions the cost of sledging is considerably reduced, as the rock does not require to be broken up to the size mentioned, and it may happen that the cost for this item disappears altogether.

223. Actual Cost of Quarrying in Road-stone Quarries.—Referring now to the results obtained in every-day practice, the following particulars are given for three different quarries from which material is taken for macadamizing purposes:—

Road-stone quarry No. 1.

Fig. 68, p. 137, shows the position and direction of the bore-holes, the height of the quarry face being 27 feet at one end and 40 feet at the other end. The rock is of a highly siliceous nature and very seamy in parts, while about 60 per cent. of the total amount of rock quarried is of a very hard and solid nature. The quantity of material required was 4000 tons.

The total cost of tirring, drilling, etc., is given in detail, and the relative cost of each item is also shown, the actual amount of rock quarried being 4158 tons.

TABLE XXII.

Actual Cost of quarrying in road-stone quarry No. 1, including sledging.

	Working Expenses.	Cost per Ton Quarried.
Tirring or stripping, ...	£35 11 1	2·05
Drilling, including traction-engine for generating steam (hired), coals, water, dressing drill-bits, depreciation of drill, etc., ...	30 11 3	1·77
Blasting—explosive (dynamite), detonators, supplying and coupling-up the wires, and time occupied in charging and tamping the shot-holes, . .	16 5 9	0·94
Sledging, ...	47 9 4	2·74
Total cost, . .	£129 17 5	or 7·50d. per ton.

This is at the rate of 7½d. per ton of rock reduced to a suitable size ready to be wheeled on to the platform of the stone-breaking machine.

It will be observed that the stripping is relatively high. This was brought about by the earth having to be shot over the face of the rock and carted a distance of over 100 yards. A considerable number of trees had also to be removed, the expenditure incurred being included in this item. The cost of the drilling operations includes the boring of breast-holes working from a staging; three days were lost owing to rain-storms, the quarry being in a very exposed situation.

Road-stone quarry No. 2.

224. Fig. 74, p. 150, shows the position and direction of the bore-holes, the average height of the quarry face being about 22 feet. The rock is of a hard and tough nature, and, although seamy in places, it is of a fairly solid character. The quantity of material required was 3400 tons.

The total expenditure incurred in this quarry is tabulated similarly to that of the previous case, the actual amount of rock quarried being 3475 tons.

TABLE XXIII.

Actual Cost of quarrying in road-stone quarry No. 2, including sledging.

	Working Expenses.	Cost per Ton Quarried.
Tirring or stripping, ...	£10 0 0	0·69
Drilling, including engine (road roller), coals, water, dressing drill-bits, depreciation, etc., ...	19 5 0	1·33
Carry forward, . .	£29 5 0	2·02

	Working Expenses.	Cost per Ton Quarried.
Brought forward, . .	£29 5 0	2·02
Blasting—explosive (dynamite), detonators, supplying and coupling-up the wires, and time occupied in charging and tamping the shot-holes, . .	15 1 8	1·05
Sledging, ...	39 0 0	2·69
Total cost, . .	£83 6 8	or 5·76d. per ton.

The tirr in this quarry was deposited about 25 yards from the working face by means of wheelbarrows. The cost of the drilling is under that of the previous case, which is accounted for by the motive power for the rock drill being supplied by one of the road authorities' steam road-rollers; the expenditure, however, includes a sum for depreciation of the engine.

The appearance of this quarry during drilling operations is shown at fig. 88, and the effects of the blasting operations, which show an excellent result, are represented in fig. 89.

Road-stone quarry No. 3.

225. Fig. 75, p. 151, shows the manner in which the bore-holes were placed; a cross-section (fig. 76) is also given, showing the general outline of the quarry face. The rock in this quarry is a hard and very tough basalt, and of a very solid nature. The amount of material required was 2000 tons, and the expenditure incurred for the quarrying operations is detailed in same way to that in the previous cases. The total quantity of rock quarried turned out to be 2102 tons.

TABLE XXIV.

Actual Cost of quarrying in road-stone quarry No. 3, including sledging.

	Working Expenses.	Cost per Ton Quarried.
Tirring or stripping, ...	£4 7 7	0·50
Drilling, including engine (hired), coals, water, dressing drill-bits, depreciation of drill, etc., ...	14 4 6	1·62
Blasting—explosive (dynamite), detonators, supplying and coupling-up connecting wires, and time occupied in charging and tamping the shot-holes,	10 2 9	1·16
Sledging, ...	28 9 3	3·25
Total cost, . .	£57 4 1	or 6·53d. per ton.

FIG. 88.—Road-stone quarry No. 2, showing drilling.

[*To face p. 172.*

FIG. 89.—Road-stone quarry No. 2, showing result of blasting operations. [*To face p. 172.*

FIG. 91.—Road-stone quarry No. 3, showing result of blasting operations. [*To face p. 173.*

The cost of tirring in this case is exceedingly low, the rock being at the surface, with a few pockets of earth dispersed over the area operated on. The drilling turns out very well, considering the extremely hard nature of the rock. The cost of blasting is above the average; the character of the rock was such that in calculating the throw 10 tons of rock were considered sufficient for each pound of explosive used.

The sledging is a heavy item, the material when blasted being of a similar size to that of the previous quarry (road-stone quarry No. 2), but the tough and stubborn character of the rock necessitated additional men being employed to break it up in order to keep the stone-breaking machine constantly at work. It may be mentioned that the rock in this quarry had defied the efforts of many contractors to put in a bore-hole, owing to the hard nature of the material. The jumpers could not be made to stand the work, 2 to 3 inches being all that it was possible to bore without re-sharpening.

The appearance of the quarry face, when the rock drill was working and previous to blasting, is shown in fig. 90, and the amount of rock dislodged after blasting is represented in fig. 91.

The cost of quarrying by machinery and blasting, as detailed on p. 170, is a mean result of working in twelve different quarries, including those just described, and may therefore be taken as an average in estimating the cost of quarrying in connection with the production of macadam.

226. All the quarries under the author's jurisdiction are worked during the summer months only, and in order to arrive at the cost when drilling and blasting operations have to be carried on during the winter season also, an allowance must be made for the short day inseparable from this time of the year, and for other circumstances. The cost of labour, which of necessity varies in different parts of the country, will also more or less affect the expenditure.

227. Cost of Quarrying by Manual Labour.—The cost of quarrying by manual labour, that is, by hand-boring, blasting with powder and fuse, including mashing or sledging, varies considerably, and may range from 10d. to 1s. 6d. per ton. For a small quantity of material, which is to be removed from the quarry in an intermittent manner, the cost of quarrying one ton of rock reduced to a size suitable for the hand-breakers may be taken at 1s. 1d. This figure, in order to make a comparison with the method described in the foregoing paragraphs, is apportioned to the several items which make up the cost of quarrying one ton of rock. The following sub-division may be taken as an average, although some of the items vary widely in different quarries. The price for such work is usually quoted and paid for at so much per cubic yard; the cost of quarrying one ton of rock, therefore, has been deduced from it.

TABLE XXV.

Cost of quarrying one ton of rock by hand-boring and single-shot blasting with powder and fuse, in the same quarries where the rock drill has been at work.

	Pence per ton.
Tirring or stripping (same as in Table XXI.)	0·68
Boring 1½-inch holes	4·19
Blasting—powder, fuse and caps	0·82
Tamping and firing—time only	0·31
Sledging or mashing	7·00
Cost per ton quarried	13·00

The cost of tirring is of course the same as in the case mentioned at page 170, and the cost of the explosive and fuse is similar to that in the case of using dynamite in machine-drilled holes and firing electrically. The cost of boring by hand, however, is about 2¼ times greater than that of machine drilling, while the mashing or sledging is 2½ times as much as when the material is blasted with a high-grade explosive having a rapid and violent action, and the shot-holes are fired simultaneously by electricity.

When, however, the material is quarried by hand for a stone-breaking machine, the amount of rock necessary to keep the machine constantly at work is such that the limited length of face in most road-stone quarries precludes the employment of a sufficient number of men to keep up the necessary daily supply of material. Even if this were possible, the risk of damaging the breaking machine and engine while blasting, and the delays occasioned thereby, would curtail the output of macadam from it considerably. Another point which militates against this arrangement, assuming it was possible of attainment, is the increased distance the material would have to be wheeled, which would necessarily increase the total cost. When the rock which is to be broken by a machine is quarried by hand, it is necessary to start the quarrying operations months before the time when it is intended to commence breaking. The quarried rock must be stored in a cairn as high as possible, so that the labour of transporting the stones to the breaking machine may be reduced to a minimum. This at least will cost 2d. per ton, which, added to the expense of quarrying, makes an inclusive price of 1s. 3d. per ton of rock stacked ready for breaking operations.

228. **Comparison of Cost by the two methods of Quarrying.**—From these figures it is evident that a considerable saving is effected by the use of machine rock drills, and blasting with high-grade explosives and electricity. The cost of quarrying by hand, as detailed in the foregoing paragraphs and on the same class of rock as the rock drill has been at work, shows in the

first instance that there is a saving of nearly 49 per cent., and when the hand-quarried material is stored, of over 59 per cent.

It is obvious that the economical results obtained in quarrying rock by the aid of machinery are undoubtedly great, while the practical advantages are none the less striking. For instance, by the employment of a rock drill in boring the necessary holes, a quantity of from 1000 to 1400 tons can be quarried in one week, including blasting; this practically places the material in a state for breaking operations. This would mean, in order to produce by hand a like quantity of quarried material, the employment of twenty-four men each day for a similar period, or a boring squad of three men would be engaged forty days in performing a like amount of work.

229. Cost of Machine-drilling Plant.—The cost of a rock drill, including tripod, weights, steam-pipes, hose, blasting machine and cables, all of which have been described in the foregoing sections, amounts to £100.

230. The Storing of Explosives.—"The Explosives Act," 1875, regulates the manner of storing explosives, and the quantity which may be stored under certain conditions. It has already been pointed out how a great saving in cost is effected by obtaining any class of explosive in large quantities, and storing them. For instance, 2000 lbs. of explosive, more particularly the nitro-compounds, when delivered in bulk will cost about 35 per cent. less than the same amount delivered in small quantities at a time.

The difference in cost on the quantity mentioned will be £50, and the saving effected may be taken at £25 per 1000 lbs. of dynamite or other nitro-glycerine compounds.

The quantity of explosives which may be kept in a store varies according to the distance the building is from what are known as 'protected works'; licenses are granted under four divisions, viz., A, B, C, and D, and are defined according to Table XXVI.

TABLE XXVI.

	A.	B.	C.	D.
'Protected Works.'	300 lbs.	1000 lbs.	2000 lbs.	4000 lbs.
From a dwelling-house, shop, room, mineral or private railway, tramway, workshop, places where explosives are kept, furnace kiln or fire, yards	50	100	150	200
If the licensee occupies these 'protected works,' or the premises on which they are situated, or if the occupier gives his consent in writing, the distances are reduced to yards	25	50	75	100
Also from any public road, or path, promenade, canal, dock, river, or sea-wall, pier or reservoir, yards	25	50	75	100

	A.	B.	C.	D.
'Protected Works.'	300 lbs.	1000 lbs.	2000 lbs.	4000 lbs.
Also from any public railway, factory, church, college, school, court, market, theatre, hospital, or public building, yards	50	100	150	200
Also from any factory or magazine belonging to Government, yards	440	880	1320	1760
And from any palace or house of residence of Her Majesty, her heirs or successors, miles	2	2	2	2

Stores may be licensed to contain 'gunpowder' or 'mixed explosives,' and for the work in connection with the production of material for road purposes, it is advisable to obtain a license for mixed explosives. The quantity of explosives under the divisions A, B, C, and D, refers to gunpowder, and when the nitro-compounds are stored, ½ lb. is allowed in lieu of each pound of powder. Thus, in division D 4000 lbs. of powder may be legally stored, or 2000 lbs. of dynamite or the other explosives of the nitro-glycerine class. If it be found necessary to store both these explosives, then a proportion of either may be kept; for instance, 2000 lbs. of powder and 1000 lbs. of any other explosive.

It is not permissible to store the means of ignition in the same place as the explosives, unless these are separated by a partition of such strength and character, or by such space, as will effectually prevent fire or explosion.

It is better, therefore, to store the detonators in a separate place or annexe situated near to the explosive store.

231. Description of Explosives Store.—The building must be substantially constructed of brick, stone, or concrete, or excavated in solid rock or earth, and not liable to ignition.

The plans of a suitable store for explosives of a 'mixed' description are illustrated in figs. 92, 93, 94 and 95. As the drawings are shown in detail it is unnecessary to give a full description of them. A few points of importance, however, will be mentioned, attention to which may save trouble and expense in the upholding of the building, in meeting any reasonable demands of H.M. Inspectors of Explosives, and in interpreting the details of construction contained in the Act.

The store should be placed, preferably, in a dry situation; the foundation ought to be built on a firm and solid bottom, composed of concrete, if necessary.

The cheapest, and at the same time a very efficient material for building a store is hard-burnt brick, and the thickness need not exceed 9 inches, unless under exceptional circumstances. The roof should be in the form of an arch, but, in some instances, it is made of timber, covered with galvanized corrugated iron, 22, B.W.G., screwed to the purlins, and bedded in

cement at the gables and wall plates, as shown in fig. 96. Ventilators of a zigzag form should be constructed in the walls below the level of the flooring, immediately above it, and also at the roof of the store, a free circulation of air being desirable to keep the explosives in good order, while at the same time it aids in preserving the woodwork in the interior of the building. These should be protected on the outside with cast-iron perforated plates or bricks, and on the inside with wire cloth. The exterior of the building should be covered with a coating of cement, to ensure its being perfectly waterproof.

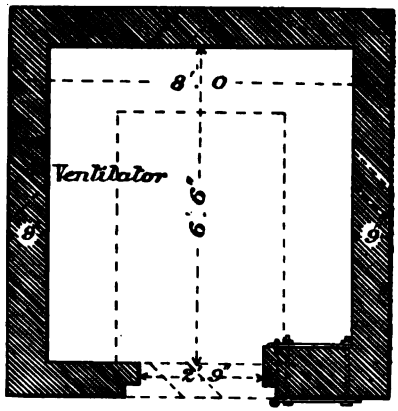


FIG. 92.—Plan of explosive store.

Double doors of wood are sometimes provided, but a door-frame of wood lined on the inside is quite sufficient. To properly protect it from being tampered with, a sheet of iron $\frac{3}{16}$ of an inch thick should be spiked on

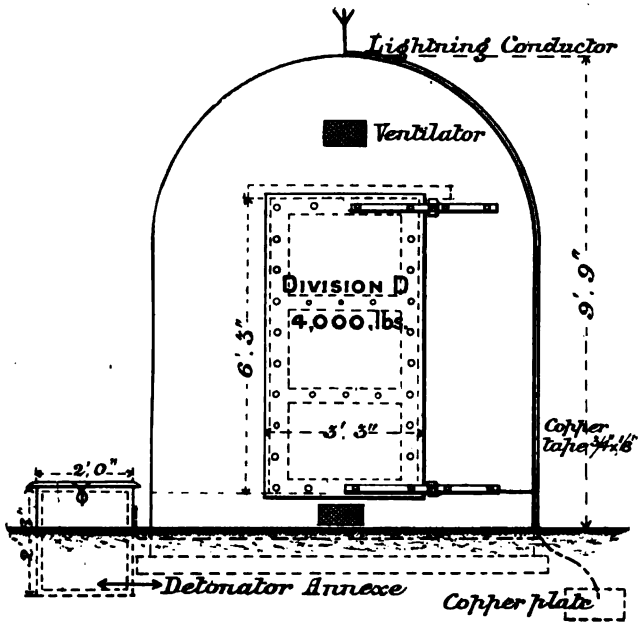


FIG. 93.—Elevation of explosive store.

to the outside of frame, so as to slightly overlap both it and the recess, which is formed of angle irons, as shown in the drawings. The side at which the

door is hung should have the brickwork 14 inches thick, while the arms forming the hinges should be fixed by through bolts and iron plates inside. The flooring must be of timber, the interior of the store must be lined with wood, and these along with the shelving must be fastened with copper, brass, or zinc nails, or with iron nails countersunk and puttied. The woodwork

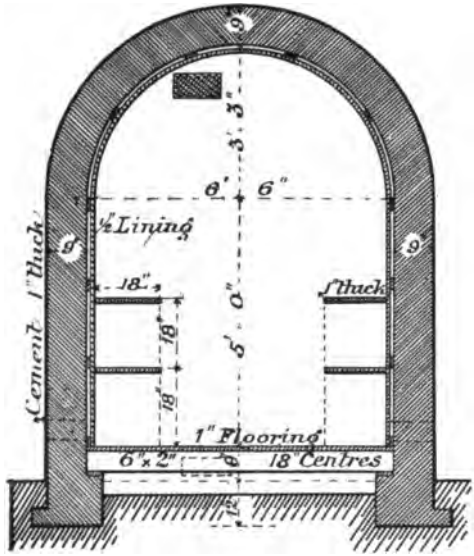


FIG. 94.—Section of explosive store.

should be finished by applying two or more coats of varnish. The lock should be of brass, and all iron, where exposed internally, properly protected. It is essential to provide a lightning-conductor, which may be made of $\frac{3}{4}$-inch round iron, or of copper tape $\frac{3}{4}$ inch by $\frac{1}{8}$ inch, properly fixed to the outside wall (as shown), and terminating in the earth preferably (damp soil),

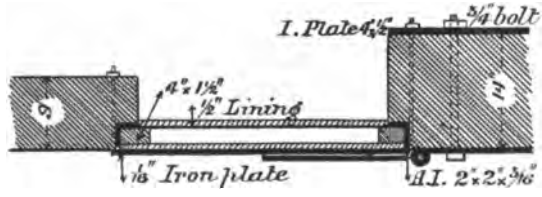


FIG. 95.—Details of door.

2 or 3 yards distant from the store, and 3 feet deep with a copper plate 20 inches by 12 inches and $\frac{1}{8}$ of an inch thick. All exterior ironwork should be put in metallic connection with the conductor, the upper end of which should be 18 inches above the highest part of the building, and terminate with three branches pointed; these should be gilded or finished with

platinum caps to resist oxidation. It is necessary to keep the floor and shelving of the store free from grit, for which purpose they should be swept periodically, and occasionally washed.

232. Annexe for storing Detonators.—The detonator 'annexe' is best formed by a box made of iron $\frac{1}{8}$-inch thick, 2 feet by 2 feet and 2 feet 6 inches deep, sunk three-fourth parts into the ground. The lid should project $1\frac{1}{2}$ inch over the box, and be slightly bent downwards at the outer edges to prevent wet gaining access. The lid should be provided with strong hinges and brass padlock. The interior of the box should be lined with wood, and have a suitable inner lid or cover. This annexe may be placed as shown in fig. 93, just clear of the wall of the explosives store. An additional safeguard in the form of a high and close fence may be erected a few feet distant from the store, completely surrounding it, and having a suitable access in front. It is necessary to provide a pair of boots without steel or iron about them, or a pair of goloshes, to be used by those entering the store. These should be of a size large enough to wear over the ordinary boots or shoes. As a convenient road to the store is a necessity, the site selected for the store will mainly depend on the facilities for making and properly maintaining such a road.

FIG. 96.—Timber roof for store with galvanized covering.

233. Cost of Erection.—The cost (exclusive of the road access) of erecting an explosives store of the dimensions given in the drawings will vary according to the place in which it is erected; but the expenditure may be taken at from £20 to £25, if the brick arch is adopted, and about £16 to £20 when the roof is formed of timber and galvanized corrugated iron, as shown in fig. 96.

234. An excerpt from the Explosives Act should be affixed on the outside fence; and the rules and regulations should also be hung up inside the store, while the class of the Division should be painted on the outside of the door in large letters in the following manner:—

DIVISION D. 4000 lbs.

CHAPTER VI.

STONE BREAKING AND HAULAGE.

Stone Breaking.

235. The material described in the preceding chapter requires a further reduction in size before it can be applied to the highways or stored for subsequent use.

236. General Conditions relative to Hand-broken macadam.—If the macadam is for coating the top of a newly constructed road, or for strengthening an existing one the crust of which has, through neglect or other causes, become reduced to such an extent that the material forming the bottoming is exposed, then it is necessary to apply metalling, the stones of which will pass through a 2½-inch ring, or weigh about 6 ounces. For general surface repairs, however, metalling of a somewhat less size may be advantageously made use of. The smaller the size the smoother will the surface of the road be; but the size of the metal for any particular section of a road must be determined to a certain extent by the amount of traffic which it will have to bear, and the nature of the rock from which the macadam is produced.

On roads over which the traffic is heavy, the tougher kinds of rock, such as basalt and syenite, should be of a size which will pass through a 2¼-inch ring; while with the same class of material, but applied on a road with only moderate traffic, the size may be advantageously reduced to pass through a ring 2 inches in diameter. The weights of these different sizes are approximately 4 ounces and 3 ounces respectively. Rock of a hard siliceous nature will give better wearing results when broken to a size somewhat larger, while flints and the harder limestones will be most suitable for surface repairs if broken to a size the weight of which varies from 6 to 8 ounces.

To ensure equal wearing, and consequently a smooth surface, the metal should be broken to a uniform size and to a form as nearly cuboidal as possible. An irregularly-sized metal cannot resist the wear and crushing effect caused by the wheels of passing traffic; consequently a bumpy surface is formed, or, in other words, it becomes 'cupped.' Under these circumstances the wear is increased, and the surface of the road becomes irregular, and horses and vehicles suffer in proportion.

237. These are briefly the main points necessary to be considered in determining the best conditions under which hand-broken metal is applicable to road repairs, especially when the material is intended to be consolidated by wheel traffic. The breaking of metal specially to a small size for ordinary repairs, although of great advantage to the road under certain conditions, increases the cost of production, and in most cases a proportionately larger amount of small stuff is produced. This fine material is of little or no value on the road, and under certain conditions its presence is pernicious; to avoid this evil it is necessary to screen the material so as to separate it from the regular-sized stones. This additional manual labour increases the cost of production, which, at a low estimate, may be taken at 3d to 4d. per cubic yard.

238. Quantity of macadam broken by Hand per Day.—A good hand-breaker can produce from 3 to 4 cubic yards of ordinary macadam per day out of such material as flints, the harder limestones, field stones, and river gravel. Whinstone of a siliceous nature, when the rock is reduced to a size similar to that mentioned in the preceding chapter on quarrying, may be broken by hand at the rate of 2 to 2½ cubic yards per day, while syenite, basalt, and the tougher kinds of whinstone can be broken up at the rate of from one-half to one cubic yard in a similar time. The number of hours which a man works when breaking road metal depends upon circumstances. If engaged on piece work a hand-breaker may work for twelve hours on a stretch, producing more material than one who is less physically capable, or who is engaged to break at so much per day.

239. Cost of Hand-breaking.—It is thus a somewhat difficult matter to arrive at the actual cost of breaking road-metal by hand, but an approximation sufficiently correct can be obtained by measuring a heap of metal which has occupied a hand-breaker a certain time to accomplish. This will give the amount broken each day of nine or ten hours; but, in addition to this, the wages which are paid in any particular locality will have to be considered as influencing the cost of production. Taking these circumstances into consideration, the experience of the author is that the cost of breaking by hand varies from 1s. 3d. to 2s. 6d. for each cubic yard of road metal. The supplying of macadam for repairing and maintaining roads under the old, or patching system, is in most cases regulated by annual contracts. The price in some instances is stated separately for quarrying, carting, and breaking; but generally these contracts are arranged for at an inclusive figure, the metalling being deposited alongside the roads at convenient points or in depôts.

The price per cubic yard of metal thus laid down will vary according to the conditions already mentioned, and, in addition, the cost of hauling or conveying it from the quarry to the roadside depôts, especially where the distance is great, may increase the price to double the actual amount of producing the macadam itself.

240. In districts where suitable rock for road purposes does not exist to any great extent, the metalling may have to be brought from a distance either by traction-engines and wagons or by rail, which, besides the heavy charges for haulage, entails in many instances double handling of the material. In those districts where local stone of a suitable quality can be obtained within a reasonable distance of where it is to be applied, the cost of quarrying, breaking by hand, and carting to the roadside depôts, an average distance of two miles from the quarry, may be 3s. 7d. per cubic yard. This is an exceptionally low figure, and can only be executed under the best possible conditions of work, while for material which is difficult to quarry, and which takes 2s. 6d. to break by hand, the cost will be 5s. 4d. per cubic yard when laid down in depôts at a similar average distance. The latter price is one that is very usually met with in practice under ordinary conditions, and as the distance to which the material has to be conveyed increases, the cost of supplying macadam may rise to 7s. or 8s. per cubic yard, and even to 16s. in exceptional cases. In quarries worked under the authority of County Councils, it is, as a rule, only necessary to pay surface damages for the ground destroyed in obtaining the materials. This amount may be allowed for either in the cost of quarrying and breaking, or stand as a separate item, but generally the additional cost per cubic yard of material is very trifling in amount, especially when the face of the quarry is high, or the relative quantity of metal removed is large compared with the area of ground occupied. In sale quarries, however, the actual cost of the material is increased by an additional charge for lordship, or quarry rent, which varies considerably, but may be taken at from 4d. to 6d. per ton or per cubic yard of rock.

241. The race of hand-breakers is, however, fast disappearing, especially in rural districts, and the high price now demanded for this class of labour requires that other means be adopted for producing macadam. The obvious necessity in these days, owing to the altered condition of trade and traffic, of attaining a higher standard of perfection in road maintenance, and of applying larger quantities of material to strengthen and improve the condition of the highways, is a further incentive to the employment of stone-breaking machinery.

242. **Requirements which a Stone-breaking Machine should possess.**—Objection has been taken against stone-breaking machines in some localities, on the ground that they fracture or crush the stones, make the edges rounded, and produce metal which is not uniform in size.

No doubt the earlier types of stone-breaking machines were open to these objections, and they may even still exist to a considerable extent in some of those employed at the present time; but they do not apply to the modern 'stone-breaker' with its almost perfect mechanical movements.

In a good machine the rock should be sledged by the upper set of jaws,

and the teeth be spaced at a comparatively large pitch and so arranged that the ridges will work in the furrows immediately opposite. The stones, after passing through the upper jaws, should be cubed by the lower ones, and means should be provided to admit of the material changing position and readjusting itself, so as to prevent spalling or the production of long thin pieces.

Provision should be made to admit of an increase or decrease of the movement of the reciprocating jaw, which acts on the rock between it and the fixed jaw.

The mechanical construction should be simple, strong, and effective, while the working parts should be so arranged as to reduce the strains on the driving shaft to a minimum. The strains should always be in one direction, while the toggles should finish in a straight line at the completion of the forward stroke. The machine and accessories ought to be capable of effectually screening the material, so that the macadam resulting from the breaking operations can be distributed, stored, or loaded automatically. In many cases where machine-broken metal is used, and condemned as inferior to that broken by hand, without the material being properly sized, it is invariably found to be caused by a want of proper sizing of the macadam by screening. To apply the stones direct to the roads as it leaves the jaws of the machine, is simply to make use of it in an unfinished state of manufacture. The appearance of a piece of rock after a hand-breaker has broken the larger-sized stones with the light mashing or sledging hammer, and before finishing his work with the small hammer, is similar in appearance to the larger-sized pieces of stone which have been only partially broken in passing through the jaws of the machine. It is the proper screening of the metalling which makes machine-broken metal a success, the larger pieces again passing through it automatically, to be broken to a proper size.

With many types of stone-breaking machines, the extent of the motion of the reciprocating jaw is constant, so that under certain conditions, as when breaking hard siliceous rock, numerous flaky pieces are produced, which, besides making a bad sample of road metal, quickly deteriorate in the road under traffic.

If a stone-breaking machine is so constructed that the pressure or blow can be regulated by either a long or a short movement, the production of flaky road metal will be reduced to a minimum. By giving the swinging jaw a short travel, by means of a rearrangement of the toggles, hard siliceous rock can be properly treated; while for tough or stubborn rock the movement should be made longer.

243. The macadam produced by a good stone-breaking machine may not present such a cuboidal appearance as that produced by hand-breaking, but for general purposes it is little inferior in quality; the cost of production,

always a determining condition in such matters, is greatly in favour of machine-broken macadam, while the possibility of producing large quantities of macadam in a short space of time is an additional advantage. In quarries where road metal is produced in large quantities, the breaking operations are carried on more or less during the whole year, for which purpose it is neces sary to fix the plant or the 'stone-breaking mill' at a convenient and safe distance from where the quarrying and blasting operations are carried on.

244. The breaking machinery should, if possible, be situated at a lower level than the quarry floor, in order to admit of the haulage of the material by bogies or cars being effected by gravitation. For a similar reason the position of the breaking plant, in regard to the disposal of the broken material, should be such as to admit of the screening being carried out immediately after the material passes through the jaws of the breaker. It can then be conveyed in shoots to the points where it is to be delivered direct into wagons or carts, or into storage bins for future use. It often happens, however, that the physical conditions of the ground will not admit of this arrangement being carried out, a circumstance which necessarily involves a system of working not so favourable as when the material can be disposed of by means of gravitation alone. When the height of the quarry floor above the level of the sidings or storage bins is such that the breaking, screening, and delivery arrangements can be properly accomplished, the haulage of the rough stones from the quarry face to the stone-breaking plant may be conveniently performed by steam haulage. When the quarry and the point of delivery are on the same level, it becomes necessary to make a suitable erection sufficiently high for the accommodation of the breaking, screening, and delivery plant: the haulage of the material to the feeding platform must in such cases be accomplished by means of a rope working on a drum, an aërial ropeway, or some other suitable arrangement.

245. A proper system of distributing the different sizes of macadam, when it is to be stored, is, of course, best carried out by gravitation; in most instances, however, it has generally to be performed by the aid of conveyors. It seldom happens that the plant can be so placed in relation to the quarry as to be so favourably situated that the haulage, tipping or dumping, and the screening and delivery of the material can be accomplished entirely by means of gravitation.

It will be evident from the preceding observations how essential it is, when laying down a stone-breaking plant, to arrange the machinery and appliances so that the cost of handling the material and operating the plant may be reduced to a minimum. These particular requirements apply more especially to quarries where a fixed plant is indispensable, by reason of the demand for macadam, and which may necessitate continuous working of the stone-breaking plant during the whole or greater part of the year.

246. The immense quantities of road metal which are produced in many of

the larger sale quarries to supply the requirements of counties and towns which do not possess suitable rock for road purposes within their own jurisdiction, necessitate the employment of a large number of stone-breaking machines at these centres.

The arrangement generally adopted in these circumstances is to make use of a 'set' of stone-breakers; the leading or 'reducing machine' having a large breaking capacity, sledges the rock to a certain size, which is then directed by shoots into two or more other machines, which break or cube the material to a size suitable for macadamizing purposes.

247. Sets of Breaking Machines.—Double, and in some cases treble, sets of stone-breaking machines are made use of in quarries where the rock is of a recognized quality, and the demand for metalling is considerable. Under these conditions the machines are fixed permanently, and, if possible, on solid foundations, as when so placed the actual amount of work performed is considerably increased compared with that obtained from machines fixed on a timber erection, which, although it may be well constructed, admits of vibration taking place when the machinery is in motion, whereby the output of the machine is reduced.

248. The original stone-breaking machine was invented by E. W. Blake, of Newhaven, Connecticut, and was introduced into England in 1860, by the late Mr. Marsden of Leeds, who effected many alterations in the construction of certain parts in his endeavour to adapt it to the requirements of this country.

Since that time many alterations and improvements in the mode of construction have been introduced by engineers, so as to reduce the strain on the working parts, and the motive power necessary to drive the machine, while the form of the jaws has been modified so as to produce cuboidal macadam.

249. Mechanical Details.—Previous to giving a detailed description of the different parts of a stone-breaking machine, it will be convenient to mention some special points which, in addition to those already stated, a machine of this description should possess.

It must be capable of withstanding the great wear and tear incidental to this class of machinery and of producing a uniform size of macadam.

The construction must be on such a principle as to avoid excessive strains on the driving shaft, and yet be simple and strong.

It must have as few working parts as possible, and the arrangement of the reciprocating jaw should be such as to admit of a sharp and powerful blow being given.

The strains brought about on the working parts when breaking stones should be maintained in one direction, and the wearing parts should be easily renewable. The breaking of the rock should be accomplished either by two machines working in conjunction, or by one with specially constructed jaws. In the former case the material is sledged or reduced suffi-

ciently small for the second machine, which cubes it to the desired size for metalling; in the latter case, the jaws are so arranged that the process of reducing the rock is accomplished by the upper jaws, while the metal is cubed by the lower ones.

The screening of the material and the conveying of the 'rejectors' or large pieces of stone back through the breaker jaws again should be performed automatically. By this arrangement the jaws of the breaking machine can be fixed sufficiently open so as to admit of a considerable number of large pieces being passed a second time through the machine, thus yielding a better sample of macadam and producing a minimum quantity of screenings.

250. Description of Blake's Original Stone-breaker. — The original Blake stone-breaker is shown in fig. 97, which represents an elevation in longitudinal section of the machine. It consists of a cast-iron frame X, with a vibrating or swinging jaw A, which approaches to and recedes from the fixed jaw B, by means of the toggles C, attached to the pitman D. It is actuated by the lever E, working on a fulcrum F, and attached to the connecting rod G, working on a crank shaft H. On this shaft are placed the fly-wheels I, and pulley J, by which the power is transmitted to the machine, the size to which the macadam is intended to be broken being regulated by the wedge K, which can be raised or lowered by the screw L working on the toggle block M; the draw back motion being

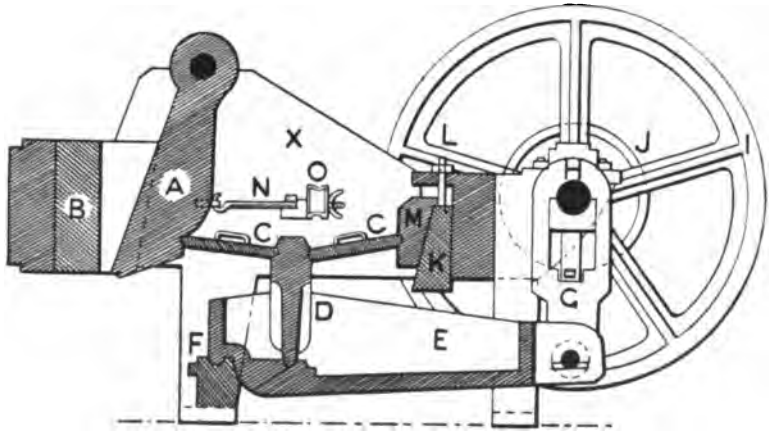


FIG. 97.—Section of original 'Blake' stone-breaking machine.

effected by means of the rod N and spring O. This machine was essentially a crusher, the teeth of the jaws being vertical and interlocking each other, so that the ridges of the one jaw were set opposite and worked against the furrows of the other. No attempt was made, by reason of the construction of the jaws, to cube the material; it was a powerful machine, however, and capable of any amount of work.

251. Archer's Breaker.—An attempt to cube the material was made by Archer, and after various endeavours he brought out a machine in 1867. It consisted of a cast-iron frame, with a slotted crank shaft—running in bearings at the end of the machine,—which operated a large lever working on a fulcrum pin. The back end of this lever was connected to the crank by a variable link, which controlled the position of the crushing faces in relation to the rotating toothed roller, fixed on a shaft and actuated by spur gearing. The front end of the lever was curved so as to partly encircle the rotating roller, and was provided with corrugated faces in the upper and lower jaws, while the teeth of the roller were placed at right angles to the corrugations in the lower jaws. This machine produced a fair sample of metal, but the wear and tear were so excessive and the number of breakages were so numerous, that it was not a practical success, while the amount of work done was considerably less than that of the Blake machine.

252. This stone-breaker was so far further improved by Archer, in that a small Blake jaw was utilized for breaking the stones, in conjunction with a lever having a curved face working against a revolving toothed-roller. At the rear end of the cast-iron lever a slotted crank shaft was fixed to transmit the motion to the machine, and on which the fly-wheels with driving pulley were secured. The crank shaft was connected by a link capable of being made longer or shorter according to the size of metal required, and fixed to the lever by a spindle. The lever rocked on a shaft, which also carried a pinion wheel; while rocking it actuated the breaking jaw by means of blocks connected by a bolt running through them from the jaw stock, and attached to the lever by an india-rubber spring and nuts. This arrangement also gave the necessary pressure to the jaws working against the revolving roller. The rotating motion of the horizontal toothed roller was effected by spur and pinion wheels driven by a belt running on a pulley fixed on the fly-wheel, and another pulley mounted on the shaft which carried the toothed roller. It is obvious that this form of construction did not follow the best and simplest mechanical movements, and although it was a decided improvement on the former machine, still the great wear of the working parts and the strains to which it was subjected when working, told seriously against it as a practical and economical macadam-breaking machine.

253. Many different forms of construction have been adopted from time to time by quarry owners and others to attain a proper working machine which would produce a satisfactory sample of macadam. The general method followed of accomplishing this was either that of using two machines, one for sledging the rock, and the other for reducing it to road metal, or of using one machine only and directing the broken material by a shoot to a system of rolls, which acted upon the long or flaky pieces of stone, reducing these to an approximately uniform size.

254. 'Excelsior' Breaker.—In the year 1872 a stone-breaking machine,

known as the 'Excelsior,' was brought from Australia to this country. The inventor, Mr. Hope, introduced special features into his machine in order to obtain a superior cubing arrangement.

This stone-breaker is shown in sectional elevation in fig. 98. It will be observed that the lower part of the swinging jaw A is curved backwards, the teeth forming the face of the jaw being continuous from top to bottom, and made to a pitch of 3 inches. The fixed jaw B had the teeth upon its upper portion placed so as to work in the furrows of the opposite jaw, while towards the lower end the teeth were altered so as to work against and opposite the ridge of the teeth in the swinging jaw. The object of this was to break the long or flaky pieces before they left the machine. The method of operating the mechanism was carried out by means of the usual fly-wheels I and pulley J, fixed to a crank shaft H. A connecting rod G attached to the crank shaft and fixed to the upper end of the rocking lever D, working on a spindle, communicated the motion to the toggle C, causing the swinging jaw to reciprocate. The drawback movement was provided for by means

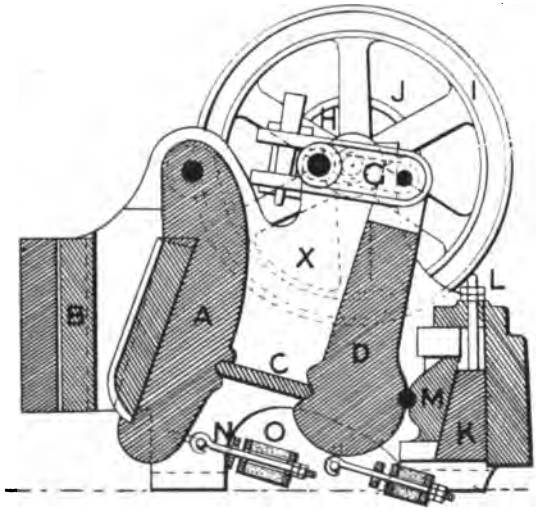


FIG. 98.—Section of Hope's 'Excelsior' breaker.

of a rod N and india-rubber spring O, the rocking lever being held in position by a similar arrangement. This stone-breaker possessed many valuable mechanical features, but, owing to the arrangement of the jaws, did not provide for the stones readjusting themselves while passing through, consequently the cubing of the material was not satisfactory.

This breaking machine was used in a few of the counties in Scotland for many years, and performed good work where the rock was of a tough and stubborn nature; but all these machines have now been superseded by stone-breakers of more modern construction.

255. The late Mr. Marsden made a further attempt to improve the cubing of the material with the Blake machine by a rearrangement in both the swinging and fixed jaws, into which three bends were introduced with alternate ridge and furrow teeth working opposite; this alteration, however, proved unsuccessful both in regard to the output of the machine and the amount of waste caused by the stones being crushed.

256. Marsden's Stone-breaker.—The design of the face of the jaws was altered to different forms from time to time as experience was acquired; the present arrangement of the teeth in the swinging and fixed jaws of the Marsden machine is shown in fig. 99. It will be observed that the jaws are composed of four parts, and can be renewed as they become worn, the break between them admitting of the stones changing their position, ensuring a better sample of macadam being produced than with jaws having teeth continuous from top to bottom. The mechanism and working of this stone-breaking machine may be thus described. The main frame X, fig. 99, is of cast iron. The swinging jaw A is suspended from a shaft and breaks the stones by vibrating against the fixed jaw B. The motion of the swinging jaw is obtained through the toggles C, working in grooves in the swinging jaw and block M, while similar grooves are made in the connecting rod G, which is made to rise and fall by means of an eccentric fixed on the shaft H, which carries the fly-wheels I and driving pulley J.

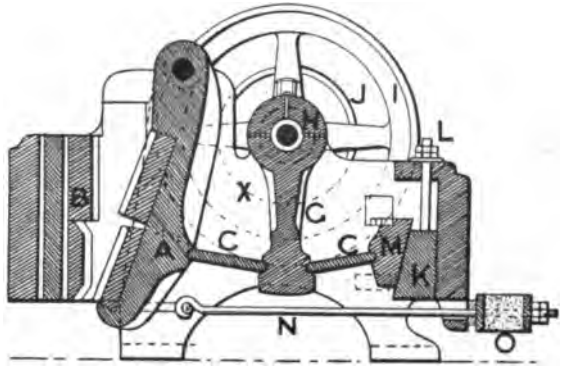


FIG. 99.—Marsden's stone-breaking machine.

When the connecting rod is at its highest point on the eccentric the toggle plates are nearly in a straight line, thus producing a direct strain through the toggle plates from the swinging jaw A to the block M. In raising the connecting rod from its lowest point, however, or when the jaws are opened to their extreme width, a considerable torsional strain is brought upon the connecting rod, and also on the shaft carrying the eccentric and fly-wheels. For this reason a crucible cast-steel connecting rod has been substituted to minimise the breakages inseparable from this form of con-

struction. To produce fine or coarse macadam, the swinging jaw can be opened or closed by means of the screw L and wedge K. The drawback movement is provided by the rod N, attached to the lower part of the swinging jaw, and fixed to the back end of the machine by means of an india-rubber spring O.

257. Blake-Marsden Stone-breaker.—Another type of stone-breaking machine, made by Marsden of Leeds, is shown in sectional elevation in fig. 100. It is known as the improved Blake, or lever hand hammer motion stone-breaker. The letters indicating the different parts of the machine are arranged as in fig. 99. The principle followed is somewhat

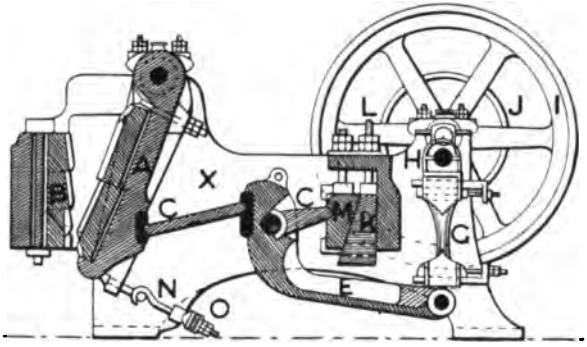


FIG. 100.—Blake-Marsden hand lever motion stone-breaking machine.

similar to that of the original Blake, but, as in all machines constructed on the lever principle, there are excessive strains due to working at high speeds, and to the rapid reciprocating action of the jaws and moving parts. The different types of stone-breaking machines made at the present time are too numerous to describe in detail, so that only a few besides the Marsden and Blake-Marsden machines will be mentioned.

258. Mr. C. E. Hall introduced a breaking machine in 1867 having a multiple action; that is, the jaws are divided into two parts vertically, and driven separately by a double eccentric on a main shaft; in other words, one jaw recedes as the other advances. The action of the connecting rod on the eccentric shaft is, as already pointed out, an objectionable feature, owing to the excessive and continual strain which it has to withstand. 'Broadbent's' and also 'Mason's' stone-breakers are similarly constructed; that is, with toggles and a connecting rod working direct on a shaft by means of eccentrics. These machines require great power to set them in motion, and also to drive them, while the principle on which the eccentric works in this class of stone-breakers is such that a considerable amount of power is lost in lifting the mechanism against the work which is being performed. Notwithstanding the mechanical defects mentioned, a considerable number of Broad-

bent's machines are working in different parts of England, especially in the Clee Hill district.

259. The stone-breaking machine which has for many years back been extensively used, and proved most satisfactory in regard to breaking capacity, quality of the macadam produced, reduced wear and tear, economical working, and the small amount of motive power necessary to drive it compared with all the others mentioned, is that patented and made by Mr. W. H. Baxter of Leeds. This stone-breaking machine combines many valuable improvements suggested by practical experience; the portable type of machine with the automatic screening and loading appliances has supplied a great want, and at the same time made certain work attainable which with the machines formerly in use was impossible.

260. Baxter's Stone-breaker.—The stone-breaker (16 inches by 9 inches) known as "Baxter's Patent Combined Portable Stone-breaking, Automatic Screening, and Loading Machine," will be described, while the actual amount of work which it is capable of performing and the cost of producing macadam will be given in detail. Various sizes of this type of stone-breakers are constructed, the largest made being known as a 24 in. by 15 in. machine, this being the size of the opening between the jaws where the rock is fed into the machine; it has a guaranteed breaking capacity of 16 tons per hour; the smallest size, 6 in. by 4 in., breaks 30 cwts. of rock per hour. The size first mentioned, namely, a 16 in. by 9 in. stone-breaker, is the most suitable machine for general use in quarries worked under County Councils, for providing macadam for renewing and repairing the highways. The breaking capacity of this machine is 60 tons per day, which amount of macadam, carted direct to the roads under repair, will provide constant work for a 15-ton roller used to consolidate the metalling. This arrangement obviates storing the material in the quarry, always an expensive operation, which will be referred to further on. A sectional elevation of Baxter's machine is shown in fig. 101. As in those already described, there is a cast-iron frame, X, having suitable flanges cast at the lower corners for fixing the wrought-iron axles, and to which the collars, swivel, and foot plate are secured, for the road wheels; while means are provided for steering at the front end.

A fly-wheel, I, is fixed to the outer end of the crank shaft H on either side of the frame, and to one of these wheels the driving pulley J is attached. The crank shaft in rotating conveys, by means of the connecting rod G, motion to the rocking lever D (the weight of which is sustained by a shaft D^1 at its lower end, on which it rocks), and actuates the toggles C C. These in turn provide for the 'knapping motion' of the swinging jaw A, which is held in position by a shaft A^1 at the upper end, and gives the necessary force to break the rock between it and the fixed jaw B. The ends of the rocking lever shaft are fitted into slide blocks placed in a rectangular recess on

each side of the frame, and are held rigidly in a vertical position by means of an iron strap and bolts. This arrangement admits of the swinging jaw being opened or closed by means of the wedge K and screw L acting on the toggle block M, and provides for the rocking lever moving laterally so as to enable long or short toggles being fixed between it, the swinging jaw, and the toggle block. Rollers are substituted in the more recent machines for this purpose with a view to reduce the friction and wear of these parts to a minimum. A positive drawback movement is obtained by the rod and chain N fastened at one end to the

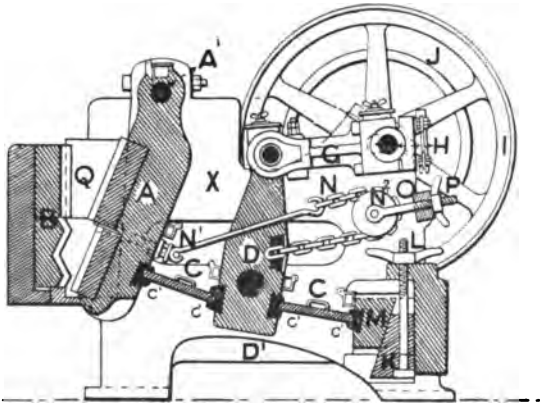


FIG. 101.—Sectional elevation of Baxter's stone-breaking machine.

through bolt N^1, which also retains the jaws in the jaw stock in proper position, and prevents them from becoming loose. The chain portion of the drawback arrangement passes over a pulley N^2, the other end being fastened to a pin in the rocking lever. This pulley is kept taut by means of a forked attachment screwed at one end, and attached at the other by a bolt and nut to the pulley. The screwed end passes through a cross-bar of wood O, strengthened by a thin steel plate, which fits into a recess at the end of the frame, the whole attachment being regulated by a handle P. The cross-bar O is purposely made elastic, so that any undue or accidental strain transmitted to the mechanism may be instantly relieved by its yielding to that strain. It will be apparent that by this arrangement the movements are all in one direction and the reciprocating parts thoroughly balanced, which in actual working saves motive power, while breakages are practically unknown when the machine is kept in efficient order. By having a positive drawback movement the undesirable india-rubber spring is dispensed with, an arrangement common to most other stone-breaking machines, which absorbs a considerable amount of power in compressing the spring to the extent required for returning the swinging jaw after the completion of its stroke.

It will be observed that the toggles working in the toggle bearings c^1, and operated by the rocking lever through the shaft, provides an intermediate

arrangement between the driving shaft and the jaws for breaking the stones. At the same time great irregularity of movement is given to the jaws by having compound toggles, and this also gives the most powerful and direct blow possible to the reciprocating or breaking jaw.

The teeth in the swinging jaw stock are made straight from top to bottom; the upper ones, 3¼ inches apart, project beyond those below them; on the face of the upper fixed jaw the teeth are also projecting, but the teeth of the lower fixed jaw are made with four bends, as shown in section in fig. 101, and are spaced 2¼ inches apart, so that their ridges work into the furrows of the teeth on the opposite jaw. The large vertical space provided by this means, and the fixing of the upper jaw in the swinging stock so as to project over the lower one, enables the material which is sledged by the upper jaws being altered in position relatively when passing through the lower or cubing jaws.

This arrangement produces a more cuboidal sample of macadam and less waste than when the teeth of all the jaws are continuous and straight from top to bottom, or where unnecessary variations of form are introduced in all the four or more jaws usually employed. The fixed jaws are retained in position by means of side wedges Q, those in the swinging stock being run in with white metal and further secured by means of through bolts. The bearings, where necessary, are provided with brass bushes, the shafts and other important parts are well protected, and give little trouble in actual working. Special means are provided for properly lubricating the working parts; this demands great care in order to prevent the admission of dust to the bushes and shafting, which, if permitted, would quickly wear out these parts.

The framework for carrying the screens, elevating belt and delivery shoot, is shown in front and end elevations in figs. 102 and 103. The breaking machine mounted on wheels with the fixings employed for retaining it perfectly rigid while at work, and feeding platform, are also illustrated.

The principal part of the framework is made of channel irons *a*, fixed on each side of the main frame of the machine, and extending to the rear of it a sufficient length, accommodates the lower revolving screen *b*, the drum *c*, for the elevating belt, and the necessary gearing for operating them. On these channels an open framework of iron bars of different section is erected as shown in figs. 102 and 103; these carry the pedestal bearings *d* for the screen *e*, elevating belt *f*, and also the delivery and return shoots *g* and *h*. The lower revolving screen is fixed on two 'spiders' which are keyed to the shaft b^1 running through them; this shaft revolves in a bearing *i* on the front end of the machine, while at the other end it runs in a pedestal bearing *j* fixed to the iron cross-bearer *k*, which also secures the channel irons together at a fixed distance apart. This shaft likewise carries the

hollow drum on which the elevating belt gyrates, and to which it is properly keyed. The revolving of this screen is provided for by means of a bevelled wheel l, fixed on the rear part of the drum in which a pinion m works at right angles to the shaft b^1 of the screen. The spindle n on which this pinion is keyed revolves in the pedestal j carrying the lower screen and

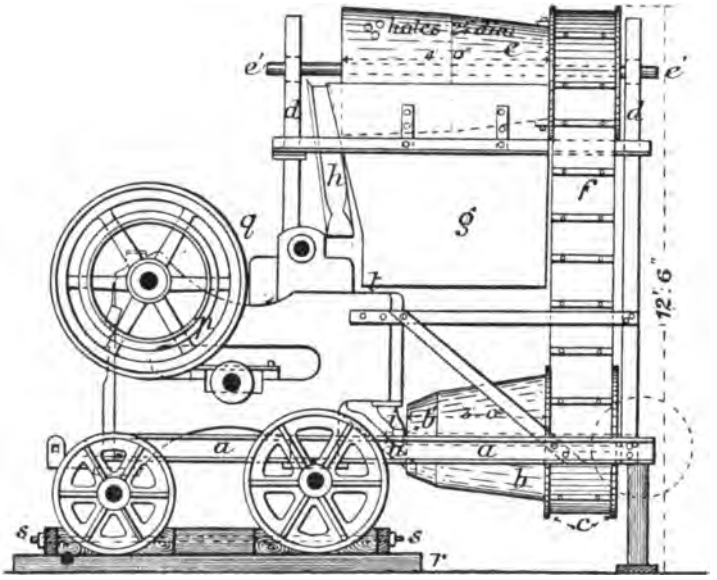


FIG. 102.—Front elevation of Baxter's stone-breaking machine.

shaft, while at the other end it runs in a bush attached to one of the channel irons, on the end of which is keyed the pulley wheel o; it is also connected by a driving-belt to the cone p, on the fly-wheel shaft h, so as to actuate the mechanism connected with the lower screen.

The top revolving screen and drum are fixed in a similar manner; the shaft e^1, which carries them, runs in two upright pedestal bearings d, which rest on, and are fixed to, the top of the bracing and bracket pedestal as shown in the figures. Wooden blocks are usually inserted between the brackets and the parts carrying them; these can be raised or lowered by wedges in order to accommodate the elevator belt to the varying atmospheric conditions. This means of raising or lowering the top screen, and consequently regulating the length of the elevator belt, can only be carried out when the machine is at rest, and may probably necessitate, should a sudden change in the temperature take place, stopping the machine to rectify this, which would involve a loss of time.

261. Lifting Arrangement for Top Screen.—The author has adopted an arrangement which prevents this delay, and also ensures the shaft of the

lower and of the top revolving screens being maintained at their proper

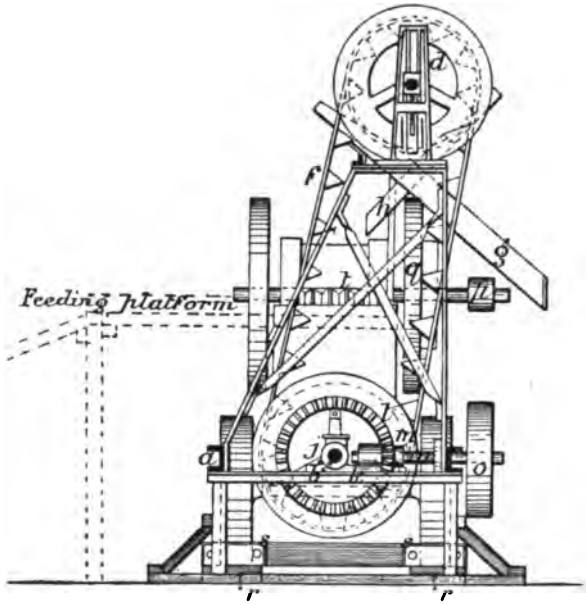


FIG. 103.—End elevation of Baxter's stone-breaking machine.

distance apart while the machine is working. This device, which is very efficient for the purpose intended, also maintains the pedestals and shaft of the top revolving screen perfectly rigid; it is constructed and operated in the following manner.

Two pedestals, *d*, are made in the form shown in fig. 104, and are bolted permanently to the top of the framework at one end, and to the bracket at the other end. Two metal blocks, fig. 104, occupy the central or open portion of the pedestal, that at A being fixed, while provision is made for the screw C working through it vertically; the block B carries the end of the shaft of the revolving screen in each pedestal, and is arranged so as to slide in a recess on either side, which secures its position horizontally. When the breaking machine is not working, the block B, carrying the top screen and drum over which the elevating belt works, is lowered towards the fixed block A, by means of the

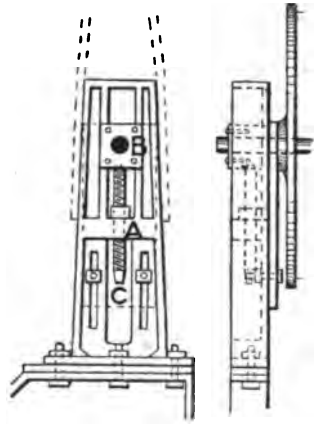


FIG. 104.—Details of lifting and lowering arrangement as applied to Baxter's machine.

screw operated by a key. Before starting work the top screen is raised at each end sufficiently high to make the elevating belt taut; the further regulating of it being carried out during the day when found necessary. By this means the shaft of the revolving screen can be kept perfectly level, which is a considerable advantage, and ensures the elevating belt working properly on the drum, thereby saving unnecessary wear.

The expansion of the india-rubber elevating belt varies according to the heat prevailing, and is considerable at times; a rise of 1 inch in the sliding-block B will represent fully 2 inches in the length of the belt.

262. The elevator belt consists of india-rubber sheet 4 to 5 ply in thickness, 16 inches broad and about 26 feet long, an allowance being made for joining the two ends by overlapping. The lifting buckets are spaced about 12 inches apart on the inner side of the belt, and are attached to it by means of plates and bolts which work between the flanges of the drums. The actual wear caused by friction on the drums is provided for by attaching strips of india-rubber sheeting about $3\frac{1}{4}$ inches wide, close to the outer edges of the inner side of the lifting belt, and against the sides of the buckets.

The portions of the elevating belt between the buckets are protected by narrow plates or by sheet iron properly attached to it.

The upper part of the delivery shoot *g* is fixed to the cross-bar, and, by another bar of iron formed as a strut, fixed to the main frame of the machine and to one of the vertical bars. The shoot is provided with sides and if necessary with a division in the centre for retaining the different sizes of macadam separately; it is also fitted with a hinged door for storing a limited quantity of metalling during the interval between the departure of the loaded carts and placing in position those which are about to be loaded. The return shoot *h* is placed so that any rejectors, or pieces too large to go through the holes in the top revolving screen, fall into it and are carried back to the jaws of the breaker.

263. Motive Power to drive Stone-breaker.—The motive power required to drive this class of stone-breaking machine, including the automatic lifting and screening arrangements, is generally provided by an 8 h.-p. (nominal) traction- or road-engine. Where a permanent breaking plant is erected the driving power is invariably supplied by a stationary engine under a suitable building to protect it from the weather and dust from the breaking machine. The power required to drive Baxter's stone-breakers may be taken at 1 h.-p. nominal for every ton the machine is guaranteed to break per hour. The cost of a plant similar to that described in the foregoing sections is £300.

The removal of the breaking machine from one quarry or depôt to another is generally performed by the same engine which drives it when breaking. Road-rollers, however, may be at times made use of for this work.

264. Setting and Working a Stone-breaking Machine.—When the

stone-breaking plant arrives at the quarry where operations are to be carried on, it is necessary, in the first instance, to place the road wheels of the breaking machine on planks, previously levelled horizontally and transversely. The site for placing the planks, and consequently the position of the breaking machine, should be selected so as to be situated centrally in relation to the heap of quarried rock to be broken. By giving this matter some little attention the length of the 'barrow runs' may be equalized, which will result in the cost of wheeling being reduced to a minimum. The wheels of the machine should be properly secured, so that there will be as little movement as possible from vibration caused by the machine when working. By referring to figs. 102 and 103 the usual method of attaining this end is illustrated.

The two planks *r r*, 12 inches by 6 inches and 10 feet long, after being properly levelled, are so spaced as to ensure that the travelling wheels will rest on them centrally. Wooden blocks 11 inches by 5½ inches, generally made in one piece, are placed on each plank between the front and rear wheels and properly formed at either end to fit the curvature of the flanges of the wheels. Two other sets of blocks, but curved at one end only, are placed in position against the front and rear wheels. Two planks, 11 inches by 3 inches, provided with ½-inch iron plates, are then placed one in front and the other at the rear. These plates serve the purpose of washers attached to the outside of the planks opposite the wheels, and should be sufficiently long to admit of the through bolts placed on either side of the wheels being properly embraced by them.

All the blocks and cross planks are kept rigidly in position by four through or side bolts 1 inch in diameter, one being placed on either side of each of the wheels and provided with screws at either end; this arrangement lends itself to speedy handling, while all the bolts are firmly secured by nuts.

The rear end of the framework at the elevating belt requires to be supported and made as rigid as possible; this is readily accomplished by means of two planks with uprights between and tied together, or they may be braced as shown in the end elevation, fig. 103.

The feeding platform is erected by fixing a few uprights about 4 feet clear of the framework; these are placed on the opposite side of the machine on which the delivery shoot is attached; the cleading, which forms the floor resting on the cross bearer of the iron framework, is fixed immediately below the level of the mouth of the machine. Side pieces of timber are fixed round the feeding platform to prevent any stones falling into the working parts of the breaker, while the top of the cleading is sometimes covered with iron plates; this precaution preserves the planks, which are otherwise quickly worn through by the incessant dumping of stones on it, and by the subsequent shovel work in transferring the material to the

jaws of the machine. Barrow runs are then arranged, having easy gradients from the quarry floor to the feeding platform, the sledged material being generally wheeled to the machine by four men, but when the distance is considerable five or six men may be required for this work. If the stone-breaking machine has been placed at a suitable point in relation to the quarried rock, a less number of men will be necessary to wheel the material to the feeding platform than when the site has been selected to suit other minor considerations. Before the actual breaking operations are commenced, the machine should be run while empty for a few minutes to ascertain if all the working parts are in proper order.

The feeding of the material into the jaws of the machine, *t*, figs. 102 and 103, is performed by two men, who place the large pieces of rock into it by hand, and the smaller material by shovels so as to keep up a steady and constant supply of stones in order that the capacity of the breaker may be utilized to its full extent, without overstraining or choking taking place. Stone-breakers, into the jaws of which the material is shot or tipped in a promiscuous manner, do not produce macadam so well cubed as when hand-fed; by the latter means the rock can be placed in the machine with due regard to its line of cleavage, while the amount of screenings is considerably less than in the former method of feeding. The material, after passing through the jaws of the machine, is conveyed by means of a shoot *u* to and passed along the lower revolving screen *b*; the dust, chips, and gravel deposited underneath are removed and placed in separate heaps at some convenient point for future use. The actual macadam, including the rejectors or large pieces of stone, and which should form a fairly large proportion, are delivered into the elevating belt and buckets *f*, and then conveyed to the top drum, where the material is discharged into the top revolving screen *c*, by means of a shoot.

265. The maximum size of the macadam will be determined by the diameter of the holes in the top screen; any stones exceeding that size must necessarily pass to the end of the screen, and, falling into the rejector shoot *h*, pass through the jaws of the breaking machine again. By judiciously opening the jaws somewhat wider than is necessary for the size of the metal aimed at, especially when breaking rock of a siliceous nature, the best sample of macadam will be obtained, and a less percentage of screenings be produced.

In quarries where the breaking machinery is placed in a permanent position, and especially where more breakers than one are employed, the material from the quarry face is generally transported to the breaking machines by means of bogies. The tram-roads are laid to and adjoin the feeding platforms; these platforms are inclined towards the jaws of the machine on to which the rock is tipped; one man guides and regulates the material into the mouth of the machines with an iron rod. Under

such circumstances the stone-breaking machines are generally (at all events those used for sledging the rock) of a comparatively large size, so that careful feeding is not so important as in smaller machines. Before detailing the amount of work done by a stone-breaking machine and the cost of production, it will be necessary to explain the means adopted in removing and replacing the jaws when they become worn, and the arrangement employed by which the top revolving screen is removed when necessary in transferring the machine from one quarry to another.

The crane arrangement for lifting out and replacing the jaws consists of two T-iron uprights fitted into recesses, and bolted to the framework on either side close to the position occupied by the jaws. At the upper end a cross-bar on edge is fitted, and a hook with block and tackle attached for lifting and lowering the jaw stock and fixed jaws. The renewing of the jaws in the jaw stock requires careful attention, as, should the white metal not be uniformly run in and around the jaws, breakage may take place when at actual work.

266. Removing Top Screen when Travelling.—The top revolving screen should for convenience and safety be unshipped when removing the machine from one quarry to another, especially in thickly-wooded districts and in places where the service roads are tortuous and rough. The process of lowering it down by means of ropes and planks is not wholly free from danger,

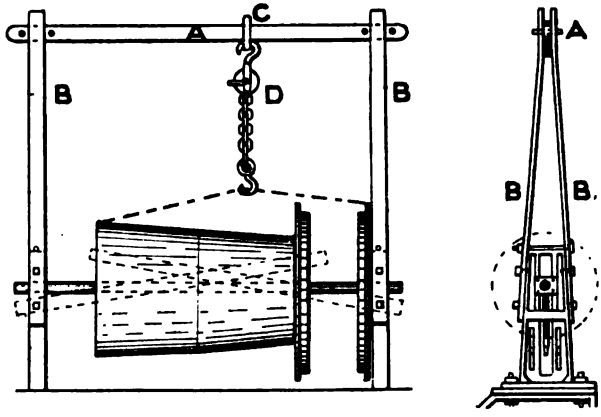


FIG. 105.—Baxter's machine; mode of removing top screen.

while the time occupied in either lifting or lowering the screen is considerable. A simple means adopted by the author for this purpose consists of two iron standards bolted to each pedestal block, as shown in fig. 105. A cross-bar A with check studs is fitted into a recess of and extends between the standards B; the hook C on this bar is attached to the block and tackle D.

The standards and cross-bar require to be of such height that when the lifting block is attached there will be ample space for the top of the screen clearing the cross-bar, and the ends of the shaft becoming disengaged from the sliding blocks in the pedestal bearings. When travelling, the height of these standards would in most cases prove inconvenient; provision is, therefore, made for the removal of one of the stud bolts on either side, so that each standard can be folded over inwards to the level of the pedestal block and secured in that position, as shown by the dotted lines in the illustration.

267. Quantity of macadam broken and cost per ton.—The amount of rock reduced by sledging to a proper size, namely 16 inches by 9 inches, which a stone-breaking machine of the size described can break in one day, will depend on the nature of the rock operated on and the number of hours the machine is at work, while the climatic conditions also enter largely into the question of the actual performance of the machine. Taking an average, based on an experience extending over a considerable number of years, the author finds, taking all classes of whinstone and basalt rocks into consideration, that it amounts to from 60 to 64 tons of macadam broken in nine hours. The amount of chips and gravel produced will necessarily vary according to the nature of the rock, and the percentage may be as high as 5 cwts. per ton of rock broken, while with material of a tough nature the amount of screenings may only be 3 cwts. per ton. The weight of the chips and gravel is ascertained occasionally, so as to fix the proportion of screenings to macadam. The average, however, may be taken as $3\frac{1}{2}$ cwts. per ton of rock broken, which will make the inclusive weight of material broken by one of Baxter's 16 inch by 9 inch automatic and screening machines from $70\frac{1}{2}$ to $75\frac{1}{5}$ tons per day of nine hours.

This may be taken at 8 tons per hour, which corresponds with the results obtained in other counties in Scotland when the work is carried on under similar conditions. The amount of the screenings, consisting of chips and gravelly material, is generally in excess of the requirements in most districts. It will be more conclusive, therefore, in arriving at the cost of producing macadam, to calculate the price of the material actually applied to the roads for renewal or maintenance purposes.

It may be mentioned, in passing, that the chips and gravel afford an excellent material for binding in connection with rolling operations, and when thus employed, or made use of for repairing footpaths, the value of the material used should be credited on the side of breaking.

For the purpose of determining the cost of producing macadam by means of a stone-breaking machine, the actual or serviceable material which can be applied directly to the roads will be considered first.

Table XXVII.

Cost of breaking macadam by machinery.

	£	s.	d.
Engineman,	0	4	0
Coals (steam navigation) for stone-breaking machine, 6 cwts., including carting an average distance of 2 miles, at 12s. per ton,	0	3	8
Carting water for stone-breaking machine, one-third day of a horse at 8s.,	0	2	8
Foreman of breaker,	0	3	8
Feeders, two men at 3s. 6d.,	0	7	0
Barrowmen (performed by contract at 2½d. per ton on 72 tons of rock),	0	15	0
Removing chips and gravel, one man,	0	3	2
Lubricants and waste for engine and breaker,	0	1	3
Allow for time lost in removing plant from one quarry to another once in three weeks, one day of whole squad,	0	2	6
Depreciation on engine and repairs, including sleeping van and water cart,	0	4	0
Depreciation and repairs of stone-breaker, including renewal of jaws, lifting belt and buckets, screens, etc.,	0	3	0
Cost of breaking per day,	£2	9	11

This is the actual expenditure, including depreciation on one day's work. If 62 tons of macadam be taken as an average day's breaking, the cost will be 9·66d. per ton.

This is increased beyond the actual working expenses by the necessity of recording the weight of the broken material, which is performed immediately after breaking, and before it is removed to the roads under repair. This is effected by means of a portable steelyard, such as Pooley's agricultural type of weigh-bridge, the parts of which are easily put together or removed; it is of a light but strong construction, and can be readily adjusted. The cost of weighing the macadam, including depreciation and repairs of the machine, may be taken at 3s. per day, or equal to 0·58d. per ton. This additional expenditure may not be absolutely necessary, but it is advisable to ascertain exactly the quantity of macadam broken each day. When the haulage of the metalling from the breaker to the highways is performed by contract, it becomes indispensable to weigh the macadam.

There are other circumstances which have also to be considered in arriving at the ultimate actual cost of producing macadam by means of a breaking machine, as, for instance, the inclement nature of the weather or a breakdown. In the latter case, if the machine is kept in an efficient state of repair and properly managed, the loss by such a possibility is

very small indeed. In the former case it will depend entirely on the weather, and as the leading hands are paid full time even during delays caused by wet weather or otherwise, it is necessary to allow a sum to cover this loss. The experience of the author is that an amount equal to 0·32d. per ton will be ample to meet such a contingency. These items summarized represent the actual cost of preparing macadam delivered into carts or wagons under ordinary conditions, and are as follows:—

TABLE XXVIII.

	Pence per ton.
Cost of breaking macadam, ...	9·66
Weighing macadam, ...	0·58
Contingencies, ...	0·32
Total cost, ...	10·56
In the event, however, of a quantity of chips and gravel being utilized in rolling or for other operations, a sum equal to say 15 per cent. of the value of the total amount of screenings should be deducted, amounting to . .	0·50
Total cost after deduction, . . .	10·06

The cost of labour and the fuel for the engines have a bearing on the total cost per ton of macadam broken, and may vary considerably in different counties and districts. The author has on many occasions accomplished this work for 9d. per ton (but the inclusive cost has generally been 10¼d.) by arranging the work to be carried out during the most suitable months of the year. If the working expenses incurred be calculated on the total amount of rock broken each day, then the cost, taking the quantity as 72 tons, would be 8·32d. per ton.

On referring to p. 181 it will be seen that the comparative cost of hand-broken macadam is 1s. 3d. to 2s. 6d. per cubic yard, or 1s. 1½d. and 2s. 3d. per ton respectively. The average, however, may be taken at 1s. 9d. per ton, which represents the price paid for this class of work previous to the introduction of stone-breaking machinery into the district of which the author has charge; but it may be incidentally remarked that the price for hand-broken macadam is now much higher. The difference in the cost of production between hand and machine-made macadam is therefore, taking 11d. per ton for the latter, nearly 48 per cent. in favour of macadam produced by a stone-breaking machine. It may be mentioned here, although the matter will be described fully in the chapter on "Rolling," that the macadam produced by a breaking machine, being properly screened, makes a much superior road surface compared to that which can be made with unscreened hand-broken metal.

If hand-broken metal be screened so as to improve its wearing capacity, then the saving in favour of macadam produced by machinery will be still greater.

268. The requirements of a district or county in regard to the quantity of macadam required for maintenance will depend in a great measure on the amount of traffic, the quality of the material used, and the mileage of roads to be repaired each year. When the quantity does not exceed 8000 or 10,000 tons each year, one stone-breaker of the construction and size described will accomplish this in from seven to eight months, allowing for the time lost by occasional wet weather and other causes. If the quantity of metalling required each year exceeds these figures, it will be more economical to employ two or more machines, so that the total quantity necessary for repairs may be broken during the summer months. One stone-breaking machine working during the whole year in different quarries will be capable of producing, in addition to the 8000 tons already mentioned, a quantity during the other four or five months of the year of from 3500 to 4400 tons, or a total for the whole season of from 12,400 to 13,500 tons of macadam.

The cost of production during the winter months will be increased considerably, and in many instances may exceed the cost of breaking the material by hand.

This does not, however, apply when fixed machinery is employed, where the work is carried on during the whole of the year, although the cost is sometimes increased by working on a short day, or even on full time at that period of the year when using the electric or other light. Under these circumstances it is usual to erect a covering over all the stone-breaking plant in order to afford shelter for the men engaged, and so admit of the work proceeding without interruption. This also protects the machinery during unfavourable weather.

269. Amount of work performed by working parts, and Cost of Renewals.—The wearing parts, namely the jaws, wedges, toggles, and toggle bearings, lower and top revolving screens, elevator belt and buckets, etc., are easily renewed; their life of usefulness will depend on the amount of work performed, the nature of the rock broken, and on the care with which the different parts of the machine are attended to.

Taking an average over many years the more important parts mentioned will, depending on the quality of the material used in their manufacture, perform approximately the following work before the necessity arises for renewing them.

TABLE XXIX.

	Tons.	Cost.	Cost per ton.
		s.	*d.*
Upper jaws (reversible), . . .	8,000	44	0·066
Lower jaws (reversible), . . .	4,000	44	0·132
Top screen, plates ¼ in. thick, . .	24,000	120	0·060
Lower screen, ...	48,000	90	0·022
Elevator belt, 5-ply, plates, etc., .	32,000	240	0·090
Buckets, set of 25, ...	8,000	40	0·060
Toggles and bearings, side wedges, etc., 1 set, ...	8,000	55	0·082
			0·512

270. The top revolving screen of the stone-breaker is usually constructed so as to produce two different sizes of macadam, and a division in the delivery-shoot provided for this purpose enables each class to be removed at will.

By this arrangement the smaller-sized macadam can be used for patching or for coating the hilly parts of the highways, but it is seldom the case that both sizes of macadam can be consolidated separately on the same road.

It therefore becomes necessary to store one or other class of macadam, which, on economical grounds, should be avoided as much as possible.

This will be apparent when it is considered that to store and refill road metal, an expenditure of from 3d. to 5d. per ton is incurred.

It is more usual, however, to have different sets of top revolving screens having perforations of a size suitable for the work on hand, so that the total amount of macadam broken may be removed direct to the roads under repair.

For general purposes a top screen having holes 2½ inches in diameter will suit the requirements and conditions of work generally, and may save the employment of other screens having a mesh of a larger or less diameter, provided the method by which the renewal or repair of the surface of the roads is properly considered, and the necessary work is arranged for in a practical manner.

The stone-breaking machine which has been described fully in the foregoing pages is the only practical machine, so far as the author is aware, combining the simplest form of construction for the efficient operations of breaking, screening, and loading. The detailed amount of work which can be accomplished by its use, and the working expenses involved in the production of macadam, are such as will compare favourably with any other make of machine for similar purposes, while the motive power necessary to work it is considerably less than in the case of most of the other stone-breakers. The latest design of this stone-breaker is shown in fig. 106.

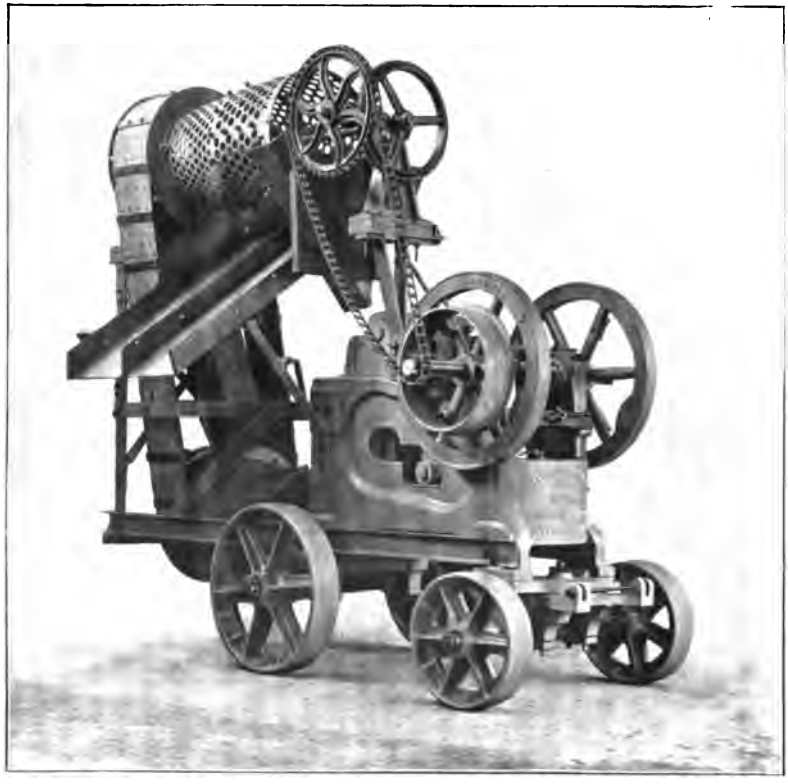


FIG. 106.—Baxter's stone-breaking machine, latest design. [*To face p. 204.*

271. Marsden of Leeds and Mason of Leicester make a form of screening and loading machine, which is so arranged that all the material broken is elevated overhead to the top revolving screen, where the dust, chips, and macadam are separated. In working a breaking machine with this arrangement it is obvious that the dust treated at such a height will be blown in every direction during the prevalence of wind, causing great inconvenience to the men engaged in working the machine. The increased carrying capacity required for the elevator belt will necessarily involve a greater motive power to overcome the friction caused by this additional weight of material being raised.

A great variety of the jaw type of stone-breaking machines are in use in the United States and other countries, all more or less constructed on the same principle as the original Blake. One form of stone-breaker differing widely, in the principle of construction and working, from the type of machines known in this country has, it is stated, been performing record work in America.

272. Gates' 'Stone Crusher.'—This machine is known by the name of the 'Gyratory Rock and Ore Crusher,' and is manufactured by the Gates Iron Works of Chicago. As the name implies, the mechanism is such that the 'crushing cone,' fitted on to a vertical or main shaft with a certain amount of eccentricity, impinges during its gyration against the material to be broken, and also approaches to and recedes from the sides of the enclosed cylindrical shell. The necessary power for operating the crusher is transmitted by bevel gearing and pinion, and is driven direct by a belt and pulley fixed on the counter shaft.

It works without the intervention of fly-wheels, such as occur in the other types of stone-breaking machines, and it is claimed that under working conditions there is little or no vibration.

It is of simple construction, and has few working parts. The strain on the gearing, however, when running at a high speed, must necessarily be very great, from which it is reasonable to suppose that great wear and tear and occasional breaking of these parts will take place. This machine, although specially designated a 'crusher,' would appear, from the construction and movement of the working parts, to create a sliding motion which would naturally subject the material to crushing. This, however, does not occur to any great extent in actual practice, the machine turning out a very fair sample of macadam.

A vertical section of the gyratory machine, known as the 'D type,' which is the latest form of crusher made by this firm, is shown in fig. 107 fixed on a timber foundation.

The principal parts of the crusher may be described as follows:—The shaft A is held rigidly at the top in the spider J, while it is gyrated by means of the bevel gearing-wheel D, the bevel pinion E, the counter-shaft

F, and the pulley G. The eccentric B admits of the shaft carrying the crushing head or truncated cone C approaching to and receding from the shell H. Inside the latter the concaves I are fixed, by which means the cone impinges the rock against the concaves. The material to be treated is

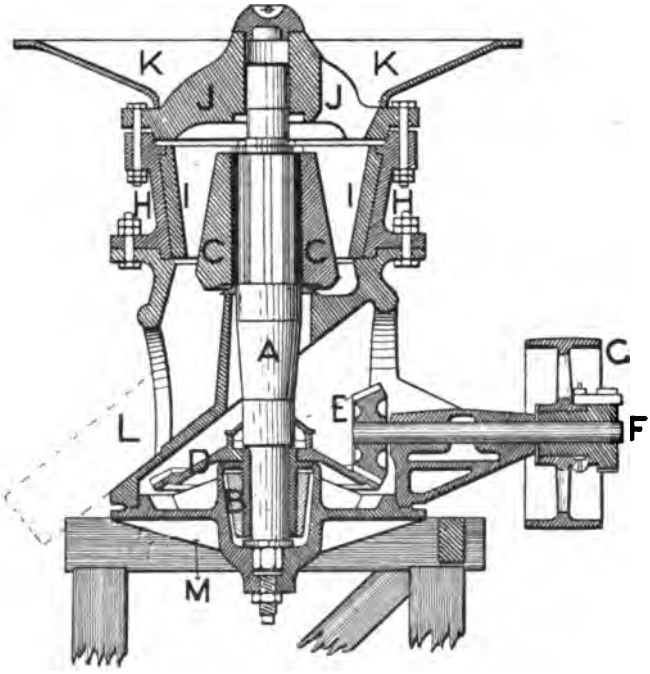


FIG. 107.—Gates' gyratory stone-crusher (sectional elevation).

dumped into the feeding hopper K, and after being broken leaves the machine by the shoot L to be elevated to the sorting sheds or screened under the foundation on which the machine rests. In the former case the whole of the broken material, of varying sizes, is distributed by conveyors into separate bins for immediate removal, or stored for subsequent use.

The foundation for this type of crusher may be of timber, mason work, or concrete, to which the bottom plate M is fixed. This class of crusher is made in different sizes, and is calculated to break from 2 tons per hour with a No. 0 machine, requiring 4 h.-p. (indicated) to drive it, up to No. 8, which is intended to break, according to the nature of the rock, from 100 to 150 tons per hour, requiring an engine with an indicated h.-p. of from 100 to 150 to drive it, including the screening and elevating arrangements.

The price of the No. 0 machine is £75 and that of the No. 8 £1400, which figures do not include the cost of the necessary foundations. This stone-crusher has not, unlike most other American inventions, been exten-

sively used in this country yet. The only recorded trial of their working, of which the author is aware, was that in open competition with a Baxter's stone-breaking machine at the Bath and West of England Show held at Bristol in June 1886. The stated capacity of the gyratory crusher (No. 5 machine) was 40 tons per hour, and it was driven by a 10 h.-p. engine, but the actual quantity of macadam produced was only at the rate of about eight tons per hour. The other stone-breaker, Baxter's 16 inches by 9 inches, guaranteed to break 8 tons per hour, actually broke at the rate of 12 tons per hour, and was driven by a 6 h.-p. engine. An extensive plant of the gyratory type has been recently laid down at the granite quarries near Dalbeattie, Kirkcudbright, and has also been introduced at Hartshill quarries, Leicestershire, and at Alderney, in the Channel Islands. It will be interesting as well as instructive to follow the actual performance of these machines on a class of rock similar to what the type of stone-breaking machines used in this country are accustomed to break into macadam, of which the quantity and cost of production are known.

Haulage.

273. The hauling or conveying of macadam from the breaking machine or quarry to the section of road under repair may be performed either by means of team labour or by traction-engines and wagons. Team work may be paid for at so much per day for each horse and cart, but is generally contracted for at a price per ton-mile, or, in other words, by results. The former method may answer to a limited extent under certain circumstances, but is not economical.

274. Cost of Haulage.—The cost of haulage is arrived at by taking the total quantity of macadam carted direct from the stone-breaking machine to the road, where rolling operations are being carried on, or in the case where the surface repairs are executed on the patching system, to the road-side depôts, and the price per ton at the average distance. The average cost is determined by the price per ton-mile, and the mean distance from the quarry to a point midway between the nearest and the furthest points of the road upon which the macadam is applied. This work is best performed by contract, the conditions generally being that tip-carts only are to be employed, and that the quantity of material which must be transported each working day is stipulated, according to the breaking capacity of the machine employed.

275. Number of Horses and Carts required.—The varying conditions of the work necessitate the employment of a greater or less number of carts during the progress of the rolling operations, depending on whether the distance is considerable or otherwise to which the macadam is to be conveyed. The number of horses and carts engaged will also depend to a certain extent on the nature of the service roads over which the material is to be conveyed. When a quantity equal to 23 or 24 cwts. of macadam is

removed by one horse each trip, allowing from eight to ten minutes for loading, the average number may be taken at six carts for every mile of travel from the quarry or depôt to the point where the macadam is to be deposited. For instance, if the metal is to be applied at a distance of 1½ miles from where the breaking operations are being carried on, nine carts will be necessary; should the distance be two miles, then the number of carts required will be twelve, provided, as already mentioned, that the weight of macadam carried by each cart is as stated.

276. The Cost of Team Haulage.—The price per ton-mile for team haulage will vary according to the condition of the roads leading to and from the quarry, and whether they are hilly or otherwise of difficult access. The cost is also affected by the relative distances to which the material is carted; that is, the price for a distance of say 1½ miles and upwards is less per ton than when the distance is under that mileage. This is brought about by the fact that in long journeys the horse is earning money with little lost time standing at the stone-breaker while the cart is being loaded as compared with a short distance from the quarry, as the time thus lost during a day's work will be greater, because in the latter case the horse returns more frequently to the quarry, and in consequence, by repeatedly losing time, less effective work is performed.

The cost of this work, in the district of which the author has charge, and embracing the experience of a number of years, shows that it may be taken at the following figures per mile, viz.:—

TABLE XXX.

	Pence.
On good service and main roads, ...	7¾
On do. do. but slightly undulating, ...	8½
On hilly roads with a good surface, ...	9½

The first of these prices may be further taken as representing the work done by a single horse taking a gross load of from 32 to 34 cwts. The figure 8½d. is applicable when the nature of the road necessitates the gross load being reduced in weight, and consequently the employment of more carts, or when it is necessary to provide occasional assistance in ascending a steep gradient. The figure 9½d. generally provides for assistance at one or more points, when the hilly nature of the roads would necessitate the average gross load per journey being considerably reduced in weight if such assistance were not provided at the points referred to. These prices are a fair average for team labour in country districts when constantly employed over considerable periods of time. In the case of such operations being carried on in the vicinity of large towns the cost of haulage will be higher to the extent of from 1d. to 1¼d. per ton-mile on the different figures given in Table XXX.

277. One great advantage resulting from this method of conveying the

material compared with that of steam traction, although the actual cost of haulage by team work taken by itself is somewhat greater under certain circumstances, is the convenient manner in which the macadam can be deposited on the road, which greatly facilitates the spreading of it. At the same time a more direct means of regulating the amount of haulage necessary can be accomplished as the work of renewal gradually approaches nearer to the point of supply by simply reducing the number of horses and carts.

278. Recording Weight of macadam broken, for fixing cost of Haulage.—The loaded carts, as already stated, pass over a steelyard, and a record of the weight is kept in a book for the purpose. The form and manner in which the weights are arranged are shown below, and a day's work is given as an example.

TABLE XXXI.

.....*Quarry*, ...19...

Weight of Empty Carts.	Contractor's Name or No. of Cart.	Number of Cart Loads and Gross Weight of each in Cwts.						Total Weight.	Total Weight of Empty Carts.	Actual Weight of Road Metal.
9½ cwts.	... or No. 1	34	33½	35¼	36½	36	35¾	211	57	154
9½ ,,	,, 2	33	32½	33¼	34	34½	35	202¼	57	145¼
10 ,,	,, 3	31½	31	31	30½	31¼	31½	186¾	60	126¾
9½ ,,	,, 4	33	35	33½	33	34	33¼	201¾	57	144¾
9½ ,,	,, 5	30¾	33½	33½	33¼	32¾		163¾	47½	116¼
9 ,,	,, 6	31½	30	30¾	31	30½		153¾	45	108¾
9 ,,	,, 7	32¼	33	32½	32½	32¼		162½	45	117½
9 ,,	,, 8	31	29½	30¼	29¼	30¾		150¾	45	105¾
10 ,,	,, 9	33¼	35½	34¼	32¾	34		169¾	50	119¾
10 ,,	,, 10	33½	33¼	34¼	33	33¼		167¼	50	117¼
								Tons .	20 ÷ 1256 . . .	62·8

It will be observed that the first four carts performed six trips, while the others accomplished only five, and the latter took the first turns the following morning and so on, equalizing as much as possible the amount of work performed by each horse.

It will also be noticed that each horse hauled on an average 23¼ cwts. of road metal, or a gross weight of fully 34½ cwts. each trip, from the stone-breaker to the road under repair. The empty carts are repeatedly passed over the steelyard to verify their weight, this being done each day during inclement weather.

279. Steam Haulage.—Steam haulage by engines and wagons presents one important advantage, under certain circumstances, as a means of con-

veying the road metal direct from the stone-breaker to the point where it is to be applied; that superiority being economy. It is imperative, however, that a suitable access be made to the quarries for this method of transporting the macadam, that the service roads be of sufficient width and strength to carry such heavy weights, and that the work should be effected during dry weather, otherwise considerable damage to the roads may be the result. In dry weather the crushing and breaking caused by the cross-bars on the driving wheels of traction-engines also at times injure the surface of the roads, and this injury the author believes would be avoided by using Boulton's patent wheels. The damage done generally to the roads by this system of hauling the material detracts from its usefulness as a means of economically transporting macadam for road purposes.

The area of the quarry floor must be sufficiently large to admit of the engine working freely, in removing and placing the wagons speedily in position so as to permit of as much time as possible being devoted to actual travelling.

For a distance from the quarry up to one mile where the metalling is to be deposited, one engine and three wagons are necessary to carry on the work uninterruptedly, one of these wagons being held in reserve in case of an emergency.

This may be considered the greatest distance which one engine can travel and return to the quarry in one hour, having regard to the time occupied in removing the loaded wagon and placing the empty one at the delivery shoot of the breaker, and the time consumed while discharging the metalling on the road under repair.

Traction wagons having a capacity of fully 6 cubic yards or 7 tons would therefore be necessary with the class of stone-breaker described, as this is the quantity of 2¼-inch road metal which it can break in an hour.

280. Cost of Steam Haulage.—The cost of steam haulage by wagons to a distance of one mile from the quarry is made up of the following items, all the plant being hired:—

TABLE XXXII.

Cost of one day's work.

Hire of engine, two men, and three wagons,	£1	3	6
Coals (steam navigation), 7 cwts., 12s. per ton,	0	4	2
Supply of water for engine, allow proportion as only being required in certain circumstances, one-fourth of a day's hire of above,	0	2	0
Man in attendance while travelling, 1 man, 3s. 4d.,	0	3	4
Allow for trimming the metal in the wagon during time it is being loaded, 1 boy, 2s. 4d.,	0	2	4
Total cost,	£1	15	4

The cost of haulage up to one mile, taking 62 tons as the daily output, would therefore be 6·64d. per ton.

When the distance slightly exceeds one mile it becomes necessary, so as to avoid storing the macadam, to employ an additional engine and set of wagons to carry on the work efficiently. This at once augments the cost of haulage by nearly 7d., or an inclusive price of 13·28d. per ton, immediately after passing the one mile limit, to be again reduced to 6·64d. per ton-mile when the distance of two miles from the quarry is reached.

It will thus be evident that when the point to which the macadam is conveyed is either one mile or two miles from the quarry, the cost of hauling is at the rate of nearly 6¾d. per ton-mile, while each ton tipped on the road between the first and second mile will cost 13½d., and between the second and the third mile it will be 1s. 8d. per ton.

In other words, the cost of transport at the succeeding distances of ¼ mile, between the first and the second mile, varies considerably, as appears from the following figures:—

	Pence.
At one-quarter of a mile beyond the first mile from quarry, . .	10·62
,, one-half ,, ,, ,, . .	8·85
,, three-quarters ,, ,, ,, . .	7·58

Again, at the two mile limit the cost decreases to 6·64d. per ton-mile, being the same as at the first mile limit. The variation in the price will be better understood when it is considered that up to one mile, which is in most cases practically the nearest distance from the quarry where the road metal can be applied, the single engine and set of wagons are fully occupied, while immediately after passing this point the two engines necessary are comparatively idle for a considerable part of the time. As the two mile limit is approached, however, the cost per ton becomes less, as there the plant is being more fully employed again.

The cost of hauling direct from the breaking machine by an engine and wagons belonging to a County Council or Local Authority can be performed for about 1½d. less per ton at the one mile limit, but to purchase extra engines and wagons for this purpose would not be economical, as, under ordinary circumstances, the time during which they would be occupied might only extend to seven or eight months each season. During the remaining months of the year there would be practically no work for this large plant, consequently no profitable results would accrue from the capital expenditure involved. Haulage by traction-engines and wagons, therefore, can only be carried out properly and economically by those possessing the requisite plant.

The arrangements for traction haulage might be carried out in conjunction with team work, in so far that immediately after passing the first, second, and third mile limit, the steam traction haulage could be supplemented by that of team labour. This method of compromising the difficulty, however,

would complicate matters very much, and at its best a considerable amount of time would be lost in loading the macadam and depositing it on the road.

It will be evident that the haulage of road metal for distances up to at least four miles by the aid of traction-engines and wagons is more economical at the different mile limits mentioned when the quantity of macadam broken by machinery has to be removed as it is manufactured, in order to save the expense of storing. When the work of applying the road metal and consolidating it are carried out at or near the limiting points described, the greater will be the economy in this particular item of expenditure.

281. When the work of hauling the material by steam power is performed by contract the price is generally 1s. per ton for the first mile, and 6d. per ton-mile for each additional mile for ordinary distances. For long distances the work can be accomplished for 4½d. per ton-mile.

282. The macadam from the breaking machine is sometimes unavoidably stored in the quarry, by reason of the supply of carts being deficient, or by delays caused when steam traction is adopted for removing the material direct to the roads.

Storing the macadam when no real necessity exists for such a procedure, or owing to any of the foregoing causes, ought to be guarded against, as the additional cost entailed becomes a serious matter when large quantities have to be so treated. The interruptions necessitating storing may be only temporary, but in any case the wheeling or carting of the metalling to some convenient point where it can be easily filled into carts or wagons at some future time cannot be accomplished for less than 1½d. per ton. The loading of this stored material into carts or wagons under favourable circumstances will cost at least an additional 1½d. per ton. When the position and level of the heap of macadam in relation to the position of the carts or wagons are such that wheelbarrows have to be employed to accomplish the work, the cost of refilling may amount to from 2½d. to 3½d. per ton. Thus the inclusive cost of storing and refilling will vary from 3d. to 5d. per ton, an expenditure sufficiently great to make the conditions imperative that storing the road metal should not be permissible, unless it is done as a matter of necessity or convenience.

If this extra expenditure be included in the cost for hauling the metalling, the figures will be increased accordingly by the actual amount incurred for this work, and this expenditure is often found to have been quite unnecessary.

283. From these observations it will be obvious that a considerable expenditure is incurred by adopting the system of employing one engine to perform the combined operations of breaking and hauling the macadam; the material being stored during the process of breaking, and when this operation is finished, utilizing the same engine for hauling purposes. When such an arrangement is permitted, the cost of storing and subsequently

refilling the macadam will amount to nearly double the sum necessary to provide two engines for these operations separately and continuously, until the necessary quantity of macadam to be transported has been accumulated.

284. From the foregoing it is also evident that it is infinitely greater economy to hire engines and wagons, and to remove the macadam as it is discharged from the breaking machine direct to the roads. Should a plant of this description not be available, the haulage should be performed by team work; this also applies to the case where such a plant can be obtained, but where the conditions are such that economy is not promoted by utilizing steam traction as a means for hauling road material.

In counties having an available supply of suitable material for macadamizing purposes within reasonable distance of any of the roads in the district, the methods of handling the macadam just described should be adopted. In the case, however, of a locality not possessing the necessary material in the immediate vicinity, it may have to be conveyed from a distance varying from 5 or 6 miles up to 20 and even 50 miles. In the latter instances the road metal is most conveniently and economically conveyed by rail. In the former case, to keep a road-roller working continuously at such a distance from the source of supply would be a serious matter. In the first place the material has to be removed from the stone-breaker to avoid storing, and in the second place the roller must be fully employed in consolidating the macadam, while the two operations involve the employment of such a number of engines and wagons as may not be available in the district.

For similar reasons the employment of team work, considering the large number of carts which it would be necessary to employ in order to prevent stoppages or otherwise hamper the operations at either point, would be difficult to obtain in most districts at a reasonable cost. It would then be necessary to adopt a system of storing the material and removing it by degrees when a suitable opportunity presents itself. Although it is not an economical proceeding, as has been shown, still, under the circumstances, it is the only practical method possible of accomplishing the end in view, having regard to what, under these conditions, may be the more economical method of the two to adopt in conveying the macadam.

285. **Wagons with Folding Doors and Hoppers.**—In steam haulage the wagons are made with folding sides to admit of the metalling being deposited into depôts, but when (as is usually the case) the macadam is to be spread direct on the road, the wagons are provided with hoppers which admit of road metal being deposited in a fairly regular manner on the centre or sides of the road.

This assists to a limited extent the spreading of the metal, but in every instance it is necessary, in order to properly mix the stones, that the macadam should be turned over by means of shovels before the rolling operations are commenced.

286. System adopted in the United States.—In the United States of America the work of transporting and spreading road metal is performed by horse wagons provided with a screw arrangement on the front of the vehicle, which on being raised causes the material to fall towards the back of the wagon, where it is discharged and distributed in such quantities as may be required. At the bottom of this distributor an adjustable iron plate, secured horizontally, regulates the thickness of the coating by being fixed at the height required above the upper surface of the material forming the bottom of a new road or the surface of an existing one.

This arrangement, the important feature of which is economy in handling the metalling, will be extremely serviceable provided the macadam composing the coating is of an equal and uniform size, but otherwise, and so long as stones composing the metalling vary in volume, even to a small extent, the work of spreading it can only be satisfactorily performed by hand labour.

CHAPTER VII.

ROAD-ROLLING AND SCARIFYING.

Road-rolling.

287.—The first important step taken in this country in the direction of advocating road-rolling by horse power as a measure of economy was set forth in a paper written by Sir John F. Burgoyne, R.E., when acting as Chairman to the Board of Works in Ireland, and published in 1843. This means of consolidating the metalling of newly-made roads was employed in that country under his directions, and may be considered the first attempt in a practical way of forming an improved road surface—not as a matter of refinement, but as a necessity. A full description of the methods followed and cost of this scientific road-rolling, which is the more valuable now, will be found in the treatise on *Roads and Streets*, by Law and Clark.*

288. Although it is recorded that the first allusion made to road-rolling in England was by one named Shotbolte in 1619, still the first practical horse-roller was made in France in 1787 by M. de Cessart, then *Inspecteur-Général des Ponts et Chaussées.*

It consisted of a cast-iron roller, 8 feet wide, 3 feet in diameter, and weighing 7000 lbs. (old French weight).

After repeated trials, the experiments appear to have been discontinued, probably owing to the disturbed political state in which France was at that time.

In the year 1817, Philip Hutchison Clay patented in this country a horse-roller, with a carriage over it, which could be loaded with weights varying from six to twenty tons.

Since that time horse road-rolling has been practised in this country, as well as on the Continent of Europe, to within comparatively recent years.

289. An interesting history of this subject, including steam road-rolling, is given by Mr. F. A. Paget, C.E., in a report to the Metropolitan Board of

* Weale's Series, 197, Appendices, pp. 318, 319.

Works, 1870,* to which the author refers his readers for a full description of the early attempts in the direction of improving the highways.

290. The difficulties inseparable from a system of rolling roads by this means, especially when a great many horses were employed, were such, considering that the weight of the rollers made it difficult to manipulate them, and that the stones forming the metal coating were displaced by the action of the horses' feet, that their introduction and employment was only practised to a limited extent, owing particularly to the great expense incurred in working them.

The application of rollers to consolidate a coat of metalling, like most inventions and innovations, has been brought about by gradual evolution. The results achieved in France by the use of horse-rollers proving in a measure successful, the further improvement of the means by which the freshly-laid road metal could be effectively consolidated, led those interested in the repairs of the public highways in that country to substitute steam for horse-power.

291. The first patent for a steam-roller was taken out in France in the beginning of 1859, by M. Louis Lemoine of Bordeaux. This steam road-roller weighed ten tons, and was steered by means of gearing and a pair of guide-wheels. Besides being used on the roads at Bordeaux, it was tried in 1860 on the roads in the Bois de Boulogne, Paris, and it was improved in different ways subsequent to 1859. In August 1860, another steam road-roller was patented in France by Ballaison, and used on the roads there by Messrs. Gellerat & Co. of Paris. In 1862, experimental trials were carried out with both these steam rollers by the French engineers of state, who, besides expressing a strong opinion in favour of steam-rolling in general, gave preference to the latter machine.

In 1865 Messrs. Gellerat & Co. of Paris designed a steam road-roller; but it is stated that, owing to the small diameter and wide roller wheels, the contour of the road was destroyed and the metalling left in ridges, not smooth as it should have been; while the cost of working was excessive, the coal consumption alone being nearly 4 cwts. per hour.

292. In 1863, Mr. W. Clark, municipal engineer, Calcutta, and Mr. W. F. Batho, Birmingham, designed and patented a steam roller; this was the first attempt made to construct a steam road-roller in this country. It was made in the latter city, and sent to Calcutta in 1864.

The principal feature of this machine was the use of three sets of rollers, two in front acting as drivers, while the third or hind wheel was set in a turn-table arrangement, being adjusted so as to steer the engine and at the same time to overlap the space between the outside driving-wheels.

* *Report on the Economy of Road Maintenance and Horse Draft through Steam Road-rolling, with Special Reference to the Metropolis*, by Frederick A. Paget, C.E., 1870.

FIG. 110.—Recent road-roller (Aveling & Porter's) with scarifier attached. [*To face p. 217.*

Two similar road-rollers, but made by Messrs. Moreland & Sons, London, were sent out to Bombay in the following year.

Many other attempts were made about this time to obtain a reliable and economical working road-roller, and even traction-engines were requisitioned and attached to cast-iron rollers for this purpose.

293. First successful Steam Road-roller made in England.—The first successful steam roller made and set to work in Great Britain was that constructed by Messrs. Aveling & Porter of Rochester, after trials in Hyde Park, London, in 1865, with an ordinary traction-engine having broad rollers substituted for the ordinary road wheels.

The steam road-roller, shown in fig. 108, was constructed for the Corporation of Liverpool in 1867; it weighed 30 tons, and its cost was stated to be £1000.

Steam road-rolling had by this time achieved some success, and the pamphlet on the subject by Mr. Paget, already referred to, greatly popularized this method of repairing roads, many of the London vestries making trials with very encouraging results.

294. First Steam Road-roller introduced into Scotland.—The first road-roller introduced into Scotland was that purchased from Messrs. Aveling & Porter by the Edinburgh City Road Trust, in 1870. The amount and cost of the work accomplished by this road-roller was the subject of a paper read at a meeting of the Engineering Section of the Royal Scottish Society of Arts, Edinburgh, by Mr. D. C. Proudfoot, city road surveyor, in 1882.

From these early and successful attempts to construct road-rollers this firm of Rochester engineers commenced to make and perfect the construction of them on an extensive scale, the leading feature being an adaptation of their form of traction-engine with an arrangement of rollers and turn-table, as shown at fig. 109.

The form and construction of the road-rollers made by Aveling & Porter have been gradually perfected from time to time by introducing important improvements and utilizing the knowledge gained from experience, producing an engine which can be easily managed, and which is economical in working.

295. The latest design of this firm's 15-ton convertible road-roller is shown in fig. 110, with one of Morrison's Scarifiers attached.

Since 1867 this Rochester firm has made and sold over 3000 steam road-rollers, varying in weight from 10 tons up to 25 tons. Most of these are working in this country; but a great number are in use in the Colonies, on the Continent of Europe and in America, while in India alone there are hundreds.

The other principal firms manufacturing road-rollers in this country are Messrs. Fowler & Co., Messrs. Green & Son, and Burrell; while in the United States the most noted are the Springfield, the Pitts, the Harrisburg and the Columbian rollers.

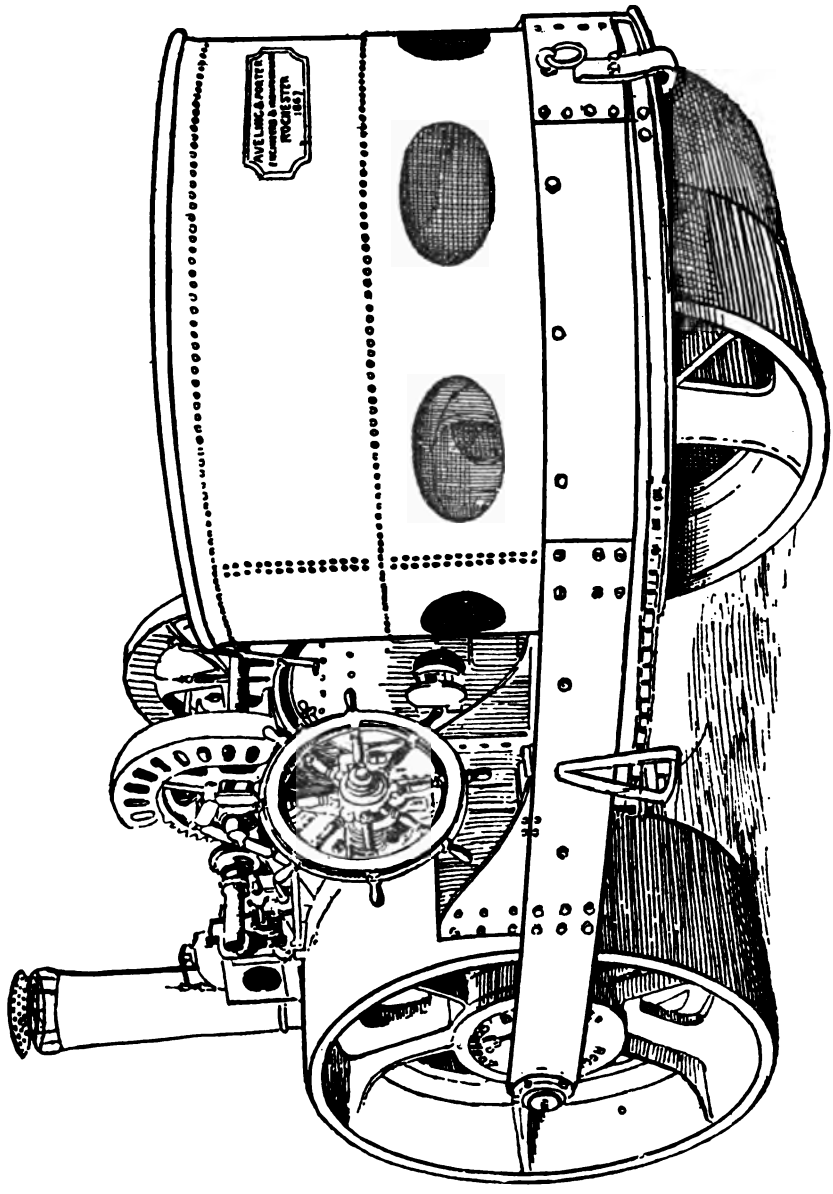


FIG. 108.—Liverpool road-roller.

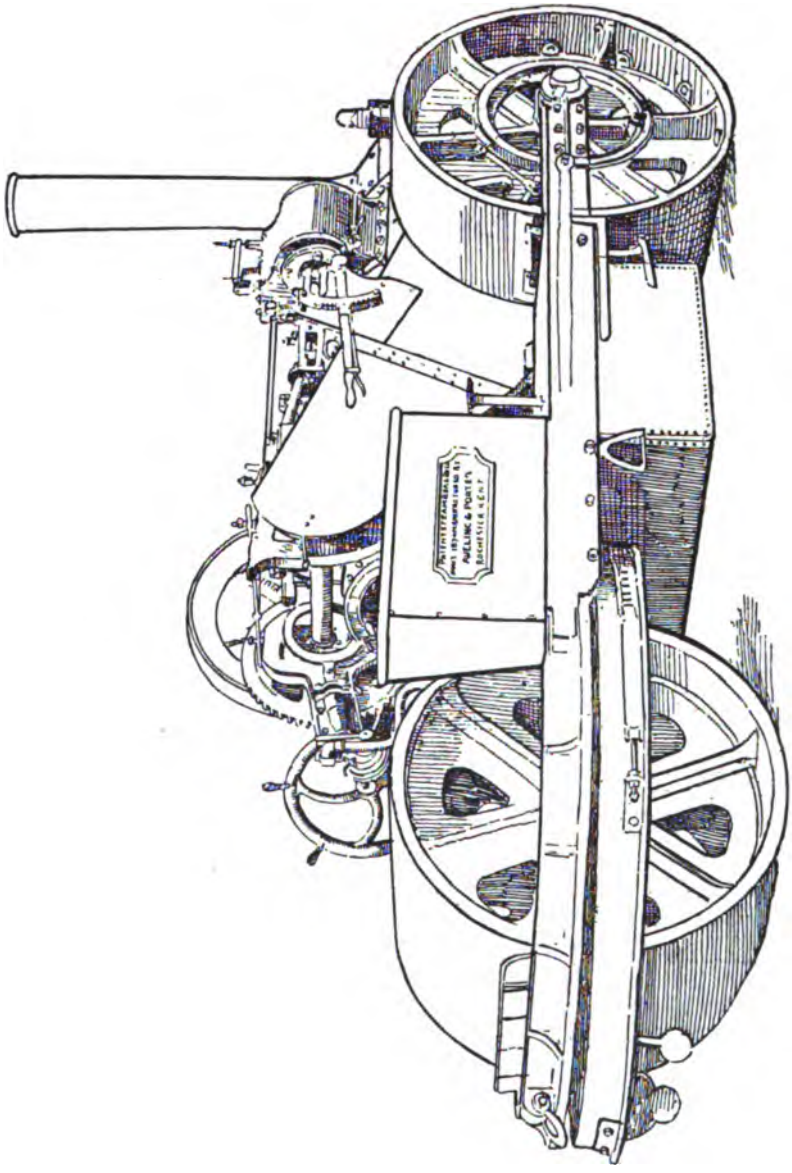


FIG. 109.—Edinburgh road-roller.

296. Advantages of Steam Road-rolling.—The advantages of road-rolling may be summed up as follows:—

(1.) The roads being made for the traffic, a saving of metalling is effected, as the stones are interlocked by the process of consolidation and present only one surface subject to wear, compared with the abrasion inseparable from the system of patching and consolidating by wheel traffic.

(2.) A harder and more regular surface is obtained, the road generally has a better appearance, ease of traction is promoted, injury and suffering to animals are avoided, and the damage to the wheels of vehicles is reduced, owing to the absence of newly-laid or loose metalling lying on the surface of the roads.

(3.) The crust of the road contains only a small amount of binding or soluble matter, wherefore there is a material reduction of the quantity of mud in wet, and dust in dry weather; and the surface of the roads do not require the constant attention which is necessary with metalling during the long process of consolidation by vehicular traffic.

(4.) Scraping and cleaning are reduced to a minimum by reason of the road being practically impervious to the effects of weather and traffic; the surface wears longer, and the absence of loose stones in dry weather secures greater efficiency and diminished cost of maintenance.

Steam road-rollers are now almost universally adopted on account of the superiority and economy of the work done, the shorter time necessary for repairs or construction, and also the indirect saving effected owing to the reduced wear and tear of horses and vehicles.

297. Different Types of Rollers made; Weight and Construction.—Steam road-rollers are made of different weights, chiefly 10, 12, and 15 tons, for use in this country, while a few rollers of 20 and 25 tons have been constructed. The former weight of roller is used in Paris, while the latter is that adopted in Madrid.

The 12-ton engine rolls a width of 6 feet 5 inches, and the 15-ton roller 7 feet 3 inches wide, and these are the class generally used in Great Britain for county work, while 10-ton rollers for the most part are employed in the larger towns, owing to the difficulty experienced in connection with gas, water, and other service pipes in the use of a heavier class of roller.

A short description of Aveling & Porter's 15-ton roller may be here given.

The boiler is of the ordinary locomotive type, the cylinder being placed on the top and at the forward end of the boiler, and surmounted with a steam jacket. The steam is taken direct from the boiler, and admitted to the cylinder without the intervention of steam pipes, thus avoiding loss in the effective pressure of the steam through being condensed.

They are made either with a single cylinder or on the compound principle, and, when necessary, can be constructed so as to convert the roller into a road engine for hauling purposes, by substituting traction wheels for the

front and rear rolls. The rear driving-wheels are 6 feet in diameter and 20 inches wide, those in front 4 feet in diameter, set close together, and having a combined width of 4 feet 6 inches. The front rolls are surmounted by a swivelling fork having a vertical spindle working in the fore-carriage bracket, which supports the front end of boiler. Provision is made for the spindle having sufficient play to admit of the front rolls accommodating themselves to the contour of the road. By means of this arrangement on the fore-carriage in conjunction with the worm-wheel and side chains, the steering of the engine is provided for, and operated from the footplate, the working of the engine being under the control of one man. The distance between the centre of the driving-wheels and the front rolls in the 15-ton convertible engine is 12 feet 6 inches, and the weight of the ordinary roller in working order, with scarifier attached, is 16¼ tons, distributed as follows, namely—two-fifths total weight on front rolls, and three-fifths of total weight on the driving or hind wheels, or fully 5 tons on each wheel. This gives the driving-wheels, when the roller is working on a level stretch of road, a compressive force of 4·88 cwts. per inch of width, being twice that exerted by the front rolls. When rolling on a gradient these latter figures will be slightly increased, owing to the effects of gravity and the weight of the water in the boiler being then greater at the rear end of the engine. The brackets for carrying the gearing are formed by the side plates of the fire-box being extended upwards and backwards in one piece, thus obviating the usual unsatisfactory method, common to many road-engines and rollers, of bolting them on to the boiler, which causes a considerable strain and injury, and consequently increases the cost of working and repairing. The wear and tear of the spur-wheels and pinions are reduced to a minimum by these being brought close together, and the combination produces the maximum of strength in the working parts. They are fitted with compensatory motion or differential gear, which enables them to be steered round sharp turns easily without slipping. Two speeds are provided, which can be thrown into and out of gear by a single operation by the driver from the foot-plate.

As previously mentioned, the steam road-roller is a special adaptation of the ordinary road locomotive either with single or with compound cylinders. Those constructed on the latter principle, although the first cost is considerably greater and repairs more numerous, are notable for their silent working, the steam first doing duty in the high, and afterwards in the low pressure cylinder. Thus the steam, in passing from the engine, is discharged into the atmosphere at a relatively low pressure, reducing to a minimum the noise from the exhaust when at work, an important matter when rolling in towns or on busy suburban roads.

An engine constructed on this principle can be started readily in any position of the crank, and there is an entire absence of sudden jerks and shocks inseparable from an engine with a single cylinder only.

It is also claimed that a considerable saving in the consumption of coal and water required is effected by a road-roller having a compound cylinder over that of one with a single cylinder only, which may result in greater economy of the working expenses, especially when the fuel has to be brought from a considerable distance, and in districts where water is scarce. Another matter of considerable importance is the reduced temperature of the fire-box, owing to the steam being expanded down before passing through the exhaust into the chimney. The fierce draught caused in high pressure or single cylinder engines creates considerable wear and tear to the fire-box and tubes, which does not occur to any great extent in engines constructed on the compound principle.

In selecting a steam road-roller for the consolidation of the metalling in making new or repairing existing roads, it is necessary to consider, in the first instance, the nature or quality of the material which is to be employed for the purpose of construction and repairs. The weight of the roller most suitable in any circumstances will, therefore, have to be in a great measure determined by the quality of the macadam made use of in the particular locality concerned.

The great object to be attained is a resulting coat of metalling compressed to such a degree, without crushing the material, that the interstices are just apparent and contain the least possible amount of binding consistent with the proper cohesion of the stones forming the coating.

To accomplish this effectually with hard and tough road metal the greatest weight of road-roller permissible should be employed which will consolidate the coating without crushing the stones composing it.

298. Experience shows that for consolidating such material as granite, syenite, basalt, and whinstone of good quality, the greatest amount and the best work are obtained by the employment of a 15-ton roller, which exerts a compressive force on the material under consolidation of from 4·88 to 5·42 cwts. per inch of width of wheel. For convenience and comparison, the weight per inch of the bearing surface of the different kinds of rollers generally employed is given in Table XXXIII.

TABLE XXXIII.

Class of Road-roller in Steam.	Weight per inch of width in driving-wheels.
15-ton road-roller, weighing in working order 16¼ tons, driving-wheels 18 inches wide, ...	5·42 cwt. per inch
15-ton road-roller, weighing in working order 16¼ tons, driving-wheels 20 inches wide, ...	4·88 ,, ,,
12-ton road-roller, weighing in working order 13 tons, driving-wheels 17 inches wide, ...	4·59 ,, ,,
10-ton steam-roller, weighing 10¾ tons in working order, driving-wheels 16 inches wide, ...	3·94 ,, ,,

299. On referring to Table VI., p. 38, it will be observed that the greatest compressive effect is produced by carts having wheels with narrow tires, amounting in the case of No. 14 to 8 cwts. per inch of width.

This is, however, exceptional, and seldom occurs in practice, or at all events should not be tolerated. In all the other cases, under normal conditions of use, the weight per inch of tire is about equal to the compressive power exerted by the driving-wheels of a 15-ton roller.

In order to obtain the best wearing results from a coat of metalling it is obviously necessary that the weight of the machine by which the material is consolidated should be greater than, or at least equal to, the displacing force or weight carried by vehicles of ordinary construction, provided the material is capable of withstanding the pressure without failure during the process of rolling.

300. Selection of Roller according to nature of Material used, and other Subsidiary Causes.—With macadam, the stones of which are of a less tough variety or of a brittle nature, such as mountain limestone, some granites, the softer descriptions of whinstone, Kentish rag, ironstone slag, and flints, the employment of a roller 15 tons in weight would result in the stones composing a coating of such material being considerably crushed, and probably rendered useless.

It is obviously necessary, therefore, to make use of a lighter roller in such circumstances, the quality of the macadam being a factor in the matter of selection.

The 12-ton roller will be found suitable for the materials mentioned in the preceding paragraph, while in some cases a roller weighing 10 tons may be advantageously used, and in particular cases this is the minimum weight which can be employed successfully. The width which the former covers when rolling is 6 feet 5 inches, while the latter rolls a width of 6¼ feet. It is for this reason that in many of the English counties rollers of different weights are employed, the material obtained locally, and used for macadam, being variable in quality, while the best class macadam for main roads is in many instances brought from adjoining counties where available, and even from centres situated at a considerable distance. The Welsh quarries supply a considerable proportion of the material necessary to the counties lying on the west coast, and many of those inland in an easterly direction, while many of the midland counties are supplied from Clee Hill and the Leicestershire quarries. The 15-ton road-roller already described is used in Scotland on county roads, almost without exception; a limited number of 12-ton rollers are employed in burghs where the matter of choice is determined not so much by the quality of the macadam as by the position and number of the gas and water mains, and also the service pipes, which are, as a rule, near the surface of the road.

The quality of the rock from which macadam is produced being for the most part of a hard, tough, and durable nature, the weight of a 15-ton roller occasions little or no damage to the material when ordinary precautions are exercised.

The amount of work performed in a given time by the different classes of road-rollers mentioned must necessarily vary, and be less in proportion as their weight and width of rolling surface decrease.

301. Quantity of macadam consolidated by Steam Rollers.—The quantity of material which a road-roller is capable of consolidating in one day will depend on the quality of the road metal and thickness of the coating applied, the amount and nature of the binding used, the available water-supply and the time lost by compulsory stoppages for the passing traffic.

A 15-ton roller, working nearly continuously, will on moderately level roads thoroughly consolidate a coating of metal 3 to 4 inches in thickness laid direct on the surface of the road under repair, without the intervention of scarifying, and using just sufficient binding to fill the interstices between the stones, from 60 to 64 tons, or about 55 cubic yards each day of nine hours' duration. When working on gradients, however, a less quantity of material can be rolled, diminishing in amount as the incline becomes steeper, owing to the artificial watering necessary for consolidating the coating escaping from the metal, and with it a considerable amount of the binding material, into the water channels and ditches, or down the inclined part of the road past where the operations are being carried on. The amount of work done by a 12- or 10-ton roller under similar conditions and time, allowing for the extra number of passages necessary to be made relatively to ensure thorough consolidation, may be taken at 40 and 30 tons respectively.

These quantities are applicable to cases where from twelve to twenty minutes are lost each hour by compulsory stoppages. When the number and gravity of such interruptions are such that a greater amount of time is consumed, as when working on suburban roads or when rolling in towns of which the streets are not given up to the exclusive use of the engine, the quantity of macadam consolidated each day will be reduced considerably, and in extreme cases the amount may not reach the figures stated by one half, or 32, 20, and 15 tons respectively.

302. Cost of Steam Road-rolling.—The cost of steam rolling depends on the system adopted, the amount of work accomplished depending on the degree of consolidation necessary, and the principle on which the chargeable expenses are calculated.

In many instances the cost is stated by some authorities on the subject at so much per square yard, varying from ½d. to 1d., but as the quantity of road metal which will cover a square yard varies according to the thickness of the material applied, it is advisable, in order to obtain reliable figures,

to calculate the cost of rolling at a price per ton or cubic yard consolidated.

The figures in Table XXXIV. may be taken as representing the different items which ought to be included in the expenses of steam-rolling continuous coatings of from 3 to 4 inches in thickness, allowance being made when necessary for local differences in the cost of labour and fuel.

TABLE XXXIV.

Cost of steam road-rolling.

Designation.	Cost per day.
Foreman, 1 man, 4s. 2d.,	£0 4 2
Engineman, 1 man, 4s.,	0 4 0
Sweepers, 4 men, 8s.,	0 12 0
Man and horse for water-cart, 8s.,	0 8 0
Coals (steam navigation), including carting, 4½ cwts., 12s. per ton,	0 2 9
Oil, waste, and brooms,	0 1 0
Total working expenses,	£1 11 11
Add for repairs and depreciation and insurance on roller, repairs on sleeping-van and water-cart,	0 3 6
Total cost,	£1 15 5

Taking the quantity of metalling which can be consolidated by a 15-ton roller in one day at 60 tons, the cost on the working expenses alone will amount to 6·38d. per ton, and when the amount for repairs and depreciation is included the cost is increased by 0·7d., or an inclusive price of 7·08d. per ton; this is equal to 7·09d. per cubic yard in the former case and 7·79d. in the latter. The working expenses in connection with a 12 or 10-ton roller are almost similar to the expenditure incurred in operating a 15-ton roller, but assuming this to be 28s. 5d. per day, and taking the quantity of macadam which these rollers can consolidate as stated at page 224, the cost per ton will be 8½d. and 11¼d. respectively, exclusive of spreading the macadam. When the road surface is prepared by being picked or scarified, and when the coatings are of less thickness than stated, the cost of rolling will be correspondingly reduced. Should the available source of the water-supply be situated at a considerable distance from where the work is being carried on, it may be necessary to employ an additional water-cart, in which case the cost of rolling will be increased by 1·60d. per ton.

The price per ton, including spreading the macadam, in the district supervised by the author has been, taking the average of a number of years, 8½d. per ton for the working expenses, but exclusive of depreciation and

repairs. If the latter be included, then the total cost per ton amounts to 9·2d.

When the work of rolling is performed by contract, the cost is generally from 10d. to 1s. per cubic yard, but this does not include spreading the macadam. The calculations in the foregoing paragraphs are based on the assumption that a suitable and sufficient quantity of binding material can be obtained in close proximity to the work on hand.

As the quality of the binding used is of vital importance, the employment of inferior material, such as road scrapings, or material of a clayey nature, should be avoided, even if the initial cost of the work should be greater when a good binding material is used.

303. Binding Materials.—Metalling consolidated with clayey or other improper matter as a binding material may present a good appearance immediately after being rolled and be otherwise an apparently good piece of work, still in damp or foggy weather a considerable amount of 'licking up' by the wheels of vehicles will take place, which reduces the strength of the coating, and causes the surface to wear unequally.

By the application of an immoderate quantity of binding of any description the coating of metal will become unsound or rotten in condition, and if this material be of an argillaceous nature, will expand during frost, owing to its absorbent properties, and cause the displacement of the metalling in wet weather. The surface will become sticky, which seriously affects the tractive power of horses, while the road itself will suffer by the irregular deterioration of the surface.

The use of such a material for binding, as mentioned, enables rolling to be accomplished in much less time than when proper binding is used, and the cost of consolidating the macadam may be reduced by 25 per cent.; but on the other hand the metal coating, which will probably contain under these circumstances from 30 to 40 per cent. of soft and soluble material, and possibly present a smooth surface immediately after being rolled, will quickly become 'cupped' by wheel traffic, a bumpy surface being the result. This is caused by the irregular wear, while the lasting qualities, or 'life,' of the coating will be shortened, giving unsatisfactory results to those travelling over the road, and the work of renewing the surface of the road in this manner may prove a failure on economical grounds. There can be no doubt, and it is now being more generally recognized, that sand as a material for binding in connection with rolling operations, when applied in a limited but sufficient quantity, promotes the durability of the metal coating, while the general results are equally satisfactory; a firm, compact, and smooth surface is obtained, and the subsequent maintenance of the road is minimised.

The difficulty and consequent cost of obtaining this kind of binding material in many districts may preclude its being used. In such cases a

material of a light and friable nature, free from vegetation, should be employed, or road-drift and the screenings from the stone-breaking machine may be advantageously employed for this purpose.

When using clean sand great care should be exercised in applying it, as in the event of its being spread over the surface of the macadam before it is 'set,' or sufficiently rolled in a dry state, the sand will be carried to the bottom of the coating by the artificial watering necessary for consolidation, and being irrecoverable, it will form an irregular and undesirable cushion between the old and new metalling. In consolidating highly siliceous macadam it is advisable to use loamy sand, in order to ensure cohesion. If clean sand be used in combination with the screenings from the breaking machine a very sound and satisfactory road surface will be obtained.

When renewing the crust of a road with a heavy coat of metalling of from 3 to 4 inches in thickness, the author invariably applies sand when possible, finishing the surface of the road with the screenings from the stone-breaking machine. This gives a smooth, clean surface to begin with, and the metal coating obtained will withstand much more wear than a coating made with an inferior binding.

A greater amount of rolling is necessary when sand is employed as a binding material, but economy is promoted, and the results are more satisfactory when sand is used than by the use of a material which gives to the metalling an appearance only of having been properly consolidated.

When the surface of a road is scarified and a coating of fresh metalling one stone thick applied, it will be found that there is no necessity for employing any additional binding materials, as the old metalling contains a sufficient amount of detritus for the purpose.

304. If the surface of a road is scarified and the old metalling screened (the method of accomplishing which will be explained in the Chapter on Road Maintenance), a sufficient quantity of small stones and fine sand or detritus will be obtained which forms an excellent binding, provided it is not incorporated with any material of a clayey nature or other unsatisfactory matter.

305. It should always be remembered that the best road is made, other things being equal, with the least possible amount of binding consistent with cohesion; provided the crust of the road is properly formed transversely and of sufficient strength, a smooth even-wearing surface and an economically maintainable road will be the result. The cost of carrying out the work of consolidating the macadam in this manner is indicated in Table XXXIV., page 225. The working expenses need not exceed the amount stated unless the binding has to be purchased and hauled a considerable distance, or there is not available a water-supply affording a sufficient quantity within easy reach of the rolling operations, necessitating extra expenditure

in the employment of additional water-carts. These circumstances will determine in a great measure the actual cost of such operations in any particular county or district of a county.

306. Mileage of Roads which can be undertaken with one Roller.—The mileage of roads which should be apportioned to each roller in a county will depend on the weight of the machine adopted, the rolling width, as also the amount and method of carrying on the work, either by patching or by spreading the macadam in long stretches the full width of the road. When working, the operations may be considerably affected by the frequency of the interruptions experienced on account of passing traffic and by the climatic conditions. It may be stated, however, that on county roads over which local or purely agricultural traffic passes, one roller will suffice for consolidating from 100 to 120 miles of road; but if the traffic is partly due to local industries, one roller is required for from 60 to 80 miles of road. In provincial towns and urban districts 40 to 50 miles would be a sufficient mileage to be properly served by one roller. In manufacturing towns and cities the extent of roads which one roller is capable of being employed on, will depend very much on whether the work can be carried out continuously or intermittently only. In the former case a full day's work can be performed, and the quantity of metalling which can be consolidated will vary according to the weight of the roller employed and the other influencing conditions; while in the latter instance possibly only one-half of the amount of macadam capable of being consolidated by the roller under ordinary circumstances may be dealt with in one day.

307. Hiring Road-rollers.—The hiring of road-rollers appears to be still a matter of controversy in some of the English counties.

The system of hiring was at one time greatly taken advantage of in England for the purpose of effecting much-needed improvements in the condition of the main roads, immediately after the passing of the Local Government Act, 1888, creating County Councils, but the more economical and satisfactory arrangement of purchasing road-rollers is now gradually being adopted. The hire system, however, is still practised in many counties at the present time, even where the mileage of the roads would ensure many road-rollers being fully employed all the year round.

The cause of this preference is somewhat difficult to guess, no valid reason being given for the adoption of hiring, except that it is cheaper to hire and save the annual cost of repairs on the rollers. This has been stated to amount to £30 or £40 per engine per annum in some isolated instances, but (admitting this to be the case) the party who supplies the rollers on hire, or contracts to perform the work at a tonnage rate, must obviously include the cost of such repairs in the charge for performing the work. The cost of annual repairs as stated above is excessive, as will be shown presently,

unless some extraordinary expenditure was included in the figures relating to the particular year for which the statistics are given. The cost of hiring rollers varies considerably, but 25s. per day may be taken as an average, which sum includes the engineman, coals, oil and waste.

Taking the quantity consolidated each day at a mean between the rolling capacity of a 15-ton roller and that of a 12-ton roller as 50 tons of metalling, the cost would be 6d.; to this sum must be added the collateral expenses for sweeping and for the use of a water-cart and horse, which amounts to 5d.; this gives an inclusive price of 11d. per ton consolidated, the price per ton increasing as the quantity of macadam rolled becomes less.

The usual contract tonnage price for hiring is 1s., so that taking the difference between the two systems at the low figure of 3d. per ton or about 25 per cent., and reckoning the useful effect of one road-roller at 8000 tons of macadam per annum, it is obvious that the expenditure incurred for hiring would be sufficient in the course of three or four years for the purchase of a roller.

308. In France, when the rolling is done by contract, the amount of consolidation considered necessary is usually stated at so many ton-miles for each cubic yard, the engine travelling at a maximum speed of 2½ miles an hour.

This varies according to the weight and width of the rolls, the average being 2½ ton-miles per cubic yard, and the contract price is about 5d. per ton-mile, exclusive of the water-supply. The necessity for hiring, however, becomes apparent when the mileage of roads under an authority or urban council is too small to justify them, on economical grounds, in purchasing a road-roller, especially when the quantity of macadam to be consolidated is only sufficient to keep it at work for a few months in each year. In Scotland all the road-rollers are purchased for county work, but hiring to a limited extent is practised in provincial towns and isolated places. These rollers were, for the most part, in use under the old *régime* of the 'Road Trustees,' and previous to the advent of the County Councils, although many road-rollers have been introduced since that date.

309. **Repairs.**—The annual cost for repairs on steam road-rollers is a subject which cannot be detailed with accuracy, as they have not been in use for a sufficient length of time.

All the working parts of an engine will necessarily require renewal in the course of time, however remote that time may be. The careful handling of the engine by an experienced driver will greatly reduce the cost of repairs, and if he is of a practical turn (as he should be) the cost for many slight repairs will be trifling.

The cost of repairs on road-rollers, used as such only, has been, in the author's experience, extending over a period of ten years, slightly under £15 for each engine, which sum includes the renewal of the driving-wheels or

hind rollers after an average wear of seven years, during which time 60,000 tons of metalling had been consolidated by one road-roller. The driving rollers are subjected to great wear, as may be imagined, and the renewal of these forms one of the heaviest items of expenditure. Various means have been devised to remedy this by adopting steel for the tires, while renewable rims are recommended by many makers of rollers. These have all more or less failed to overcome the difficulty, as the renewable tires, although appearing to satisfy the requirements in practice, are unfortunately found to be wanting in many essential particulars.

In all probability a new fire-box, tubes, and other minor parts will be required in the course of a few years; so that the actual cost of steam road-rolling may be somewhat more than the sum just stated. An inclusive sum (having regard to the probable future requirements of renewals and repairs) of £23 per annum for each roller should be sufficient to keep it in efficient working order. This is at the rate of 5 per cent. on the purchase price of a 15-ton roller. The only other direct and available information on the subject of a reliable nature, so far as the author is aware, is detailed in a paper by Mr. E. T. Hooley, County Surveyor of Notts,* on 'Steam Rolling,' which, besides alluding to the matter of repairs, describes in a lucid and exhaustive manner the history of steam road-rollers, and the work performed by them generally.

Mr. Hooley states in effect that after five years' service it was found necessary to send the rollers, three in number, to the makers' works to be thoroughly overhauled and supplied with new sets of wheels. The total cost of these repairs and renewals amounted to £388, 18s., which is equal to an annual expenditure of 6 per cent.; when returned the rollers were practically as good as new.

310. Judging by the number of steam road-rollers at present in use an idea may be formed of the high appreciation of road-rolling in this country, when it is stated that the firm of Aveling & Porter alone have made and sold over 3000 steam road-rollers, the majority weighing from 10 to 15 tons. In London alone more than 100 rollers are in daily use on an area of 400,000,000 square yards of macadamized and flint roads, which represent over 2000 miles of road having an average width of 30 feet.

311. The cost of steam road-rollers and accessories are detailed in the subjoined table, which applies only to the usual type of machine used; special requirements to suit particular circumstances involve a larger cost

* A paper on 'Steam Rolling' read before the Incorporated Association of Municipal and County Engineers, and published in their *Proceedings*, vol. xxii. p. 284.

TABLE XXXV.

Description of Plant.	Cost of Roller and Accessories. £	s.	d.
15-ton road-roller, single cylinder,	460	0	0
15-ton road-roller, single cylinder, convertible, with roller wheels only, no traction wheels or fore-carriage,	600	0	0
Set of four traction wheels and fore-carriage,	75	0	0
12-ton road-roller, single cylinder,	400	0	0
12-ton road-roller, single cylinder, convertible, with roller wheels only, no traction wheels or fore-carriage,	525	0	0
Set of four traction wheels and fore-carriage,	65	0	0
10-ton road-roller, single cylinder,	375	0	0
If made compound, extra, 15-ton roller,	75	0	0
,, 12 ,,	55	0	0
,, 10 ,,	55	0	0
,, 15 tons convertible,	80	0	0
,, 12 ,,	60	0	0
Sleeping-van to accommodate four men,	75	0	0
Traction wagon, capacity 4 tons,	65	0	0
,, ,, 6 ,,	75	0	0
,, ,, 8 ,,	85	0	0
Water-cart, ,, 240 gallons,	35	0	0
Scarifier attached to any class of roller,	100	0	0

Scarifying Macadam Roads.

312. Scarifiers or Machines for Breaking up Macadam Roads.—In repairing the surface of a road by the aid of a road-roller, the usual practice is to lay a sufficient thickness of metalling to bring the contour of the road into proper form, which often involves the application of considerable quantities of material. Laying macadam one stone thick on a hard road and then rolling it, is not to be recommended, both on economical grounds and because great damage often results from the metalling being crushed when so spread. If the surface of a road is loosened to a sufficient depth preparatory to re-forming and applying the macadam, one stone thick may suffice to meet the requirements of the case, which, without this being done, would require a coating of metal of unnecessary thickness being applied to ensure satisfactory results.

313. It seems strange that, even before steam rollers were introduced, a contrivance for scarifying roads on the agricultural harrow and plough principle was patented in 1817 by Clay, and designated "a harrow which is intended to scarify the uneven part of any road."

It is stated that attempts have been made from time to time, not only in this country but also in France, to construct a machine having the same object as Clay's, and drawn by horses, but it is evident that little or no advance was made in the construction of a practical machine for this purpose until within comparatively recent years.

314. The propriety of scarifying macadam roads does not appear to be fully appreciated, owing probably to a want of experience in the matter, or possibly to its having been so rarely resorted to that the actual work performed by the machine has not been sufficiently known.

In districts where macadam scarifiers have been introduced and practically applied, it is considered to be an indispensable adjunct in connection with steam rolling. This is a subject of considerable importance in connection with the maintenance of roads, and as such operations can be executed by machinery at a considerably less cost than by hand labour, a full description will be given of mechanical scarifiers and of the results obtainable by their use.

315. Qualifications which a macadam Scarifier should possess.—A macadam road-scarifier, to be of any practical advantage, must be of a light but strong construction, easily manipulated, and form part of, or be permanently attached to, the road-roller or traction-engine.

It should be capable of being used both when the engine is moving forward and when it is moving backward, while the engine wheels should not be allowed to compress the portion of road just broken up when making a fresh 'cut' parallel with it.

The teeth or tines should be spaced sufficiently close to ensure the crust of the road being completely loosened, and the mechanism regulating the depth of the cut should be so arranged that the teeth or tines can be instantly raised clear of the road when necessary. This is particularly desirable when working in towns in order that crossings, gratings, tobies, or other obstructions may be safely passed while the engine is in motion; the depth to which it is intended to penetrate the macadam will depend on circumstances, but for all practical purposes it need not exceed 5 inches. The working of the machine should be so arranged as to avoid the stones composing the crust of the road being violently strewn about, with the possible risk of incurring danger to pedestrians and vehicular traffic, or damage to house or shop windows when working in populous places. The best known scarifying machines made within the last few years in this country and employed in some instances with marked success, are given in the following list in chronological order.

316. Different Makers of Scarifiers.—Rutty's road-scarifier, 1884; Voysey & Hosack's apparatus for breaking up streets, etc., 1890; Jackson's road-scarifier, 1891; Wallis's machine for breaking, etc., the surface of roads, 1891; Henderson's macadam road-breaker, 1891; Messrs. J. Fowler & Co., road-scarifier, 1894; Morrison's (Aveling & Porter) road-scarifier, 1895; Rutty's road-scarifier, 1896; Burrel & Rutty's road-breaking machine, 1897; Fowler's scarifier, 1897; Marshall's scarifier, 1898; Bomford's scarifier, 1898; Hosack's scarifier, 1898.

Of the various machines mentioned, the author will describe the main

features of Rutty's original scarifier as improved in 1894, and give the amount and cost of work effected by its use. This machine has done excellent work for many years past, and still maintains its position as a capable and effective mechanical appliance under certain conditions. These conditions will be referred to later on.

Morrison's machine, which is manufactured by Messrs. Aveling & Porter, and fixed to their road-rollers or traction-engines, will also be described, and details given as to its working capacity and cost.

This machine is capable of performing heavy or continuous scarifying, and of working with equal facility and advantage backwards or forwards. As it is usually attached to the engine, but can be detached in a few minutes if necessary, it is available for work at a moment's notice; this is a convenient arrangement when the repairs on the roads are carried out on the patching system.

The other machines mentioned in the preceding list, so far as any special features possessed by them are of interest, will be briefly noticed in their chronological order.

317. Rutty's Scarifier.—The general features of this machine are shown in fig. 111. It is made up of a heavy cast-iron box or trolley *a*, to either end of which a bracket *b* is fixed, carrying the boss *c* through which the quick-threaded screw *d* in the depth-regulating frame *e* works. This frame is rigidly held in position by deep recesses on each side, between

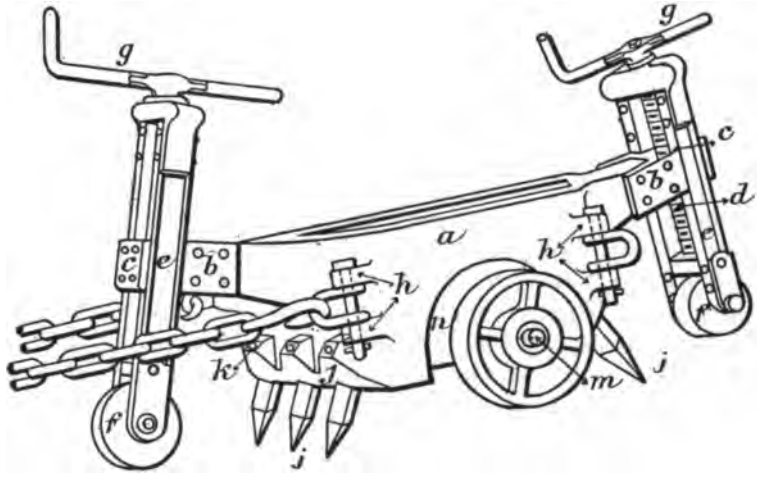


FIG. 111.

which the boss slides, the lower ends being carried by small road wheels which travel in a line with the axis of the machine, while the means of regulating the depth is provided at the upper end of the frame *e* by a handle *g*. The regulating-frame and bearing-wheel *f* are placed in a

raking position, as shown in the illustration, fig. 111. Lugs, *h*, are cast on the box-frame at the corners, to which are attached draw-links and pins, forming the means for attaching the drag-chains. The teeth or scarifying tools *i*, are placed in sockets *j*, and pass through the lower part of the cast-iron frame *a*. They are generally set at an angle of 60° with the road, and are held firmly in position by means of screws *k*. The road wheels for supporting the box-frame *a* are carried by an axle *m*, which can be adjusted transversely, so as to permit of the wheel being placed in the recess *n*, by which means the machine can be worked close up to the kerb-stones or edge of footpaths when necessary. This scarifying machine is capable of penetrating hard macadam to a depth varying from 1½ inch to 5 inches. The work is commenced at the crown of the road, and gradually continued towards the side; when the other portion is commenced the engine hauling the scarifier is turned round or reversed if necessary. The width of the cut or extent of surface loosened each turn is about 18 inches. This machine being on the trailing principle, cannot be pushed backwards; the engine, therefore, has to be disconnected from the scarifier when the length of road operated on has been traversed. To avoid the necessity of turning the engine completely round, a draw-gear arrangement is fixed on the front of the engine, by which the scarifier is drawn when making the return cut. It will be obvious that even with this arrangement a considerable loss of time is involved when operating on a short length of road. The time occupied in changing the position of the engine will depend greatly on the aptitude of the driver, but generally it may be taken at 25 per cent. of the actual working time engaged on a piece of road of about three hundred yards in length. The latest arrangement in connection with working this scarifier is to harness it to an engine in front of the driving-wheel and alongside of the steering-wheels. It is held in position, as far as it possibly can be so under the circumstances, by means of chains attached to the side of the fork, the spindle for carrying the hind wheel scrapers, and a bar of iron fixed at rear of the tender. By this means the scarifier can be hauled in either direction without reversing or turning the engine. The great width occupied by this combination, is, however, rather a serious matter on narrow roads. This machine, which weighs 2 tons, performs its work very effectively, and there is little ridging of the macadam when the teeth are working at an average depth; the latest make of this machine has four tines, which are capable of loosening a width of 21 inches; the cost of this scarifier is £100 delivered.

318. **Voysey & Hosack's Scarifier.**—This machine consists of a double cast-iron frame, the inner or tool frame working within the external one. The front part of the external frame is attached to the tender of the engine by means of a pivot shaft, while at the rear or hind part it is carried by small road wheels.

The road surface is scarified by means of an arrangement consisting of a

revolving barrel, in the periphery of which are sockets for holding the tools or teeth, which teeth are inserted and secured rigidly in position by screwing the discs forming the tool barrel tightly together by means of a through bolt and nut.

The rotary motion is obtained by a series of endless pitch chains extending from a chain wheel attached to the counter-shaft outside the fly-wheel of the engine to the shaft wheel at the front end of machine, which operates the axle carrying the tool barrel and fixed between the cast-iron frame. The tool-barrel frame can be made to traverse the external frame so as to enable the machine to work close to the side of the channels.

The depth to which it is intended to lift or scarify the macadam is regulated by means of a screw and handle. The barrel containing the teeth or tools revolves in a direction contrary to that in which the wheels of the engine travel. This machine can be worked in either direction without uncoupling the scarifier from the engine, the motion of which is alternately a pull and a push. The teeth in the tool barrel are arranged in spiral lines around it, the number inserted depending on the hauling capacity of the engine to which the machine is attached and the hardness of the road surface which is being scarified.

The machine is well balanced, and throws but little weight on the engine operating it. It can scarify at the rate of 300 square yards per hour, even when the passing traffic causes considerable delay. The action of the scarifying teeth or tools is such that stones are occasionally strewn about.

319. Jackson's Scarifier.—This machine weighs 3½ tons, and is somewhat similar in appearance and construction to Rutty's scarifier, the principal difference being that the road wheels at either end act as steering-wheels also, instead of being used in connection with the depth-regulating arrangement. Experience, however, shows that such an arrangement, so far as the steering is concerned, is not a necessity in this class of road-repairing machinery.

A lever on the top of the machine enables the scarifying teeth to be quickly lifted clear of the road surface when manhole covers or other such fixtures are met with. The scarifier can break up 300 square yards of macadam road in an hour, when the surface has been previously well watered. The cost of working this scarifier, including hire of engine, repairs to machine and tools, is stated to be $\frac{7}{10}$ of a penny per square yard.

320. Wallis's Road-pecking Machine.—This scarifier in its improved form is attached to the rear end of the tender of a road-roller by means of brackets and spindle or hinge, which admits of a rise-and-fall movement being given to the machine, and a certain amount of lateral play is provided in the arrangement of the drawbar. The machine proper is carried by two road wheels. The pecks, three in number, act when at work in a similar manner to the cutting tool of a rock drill. These pecks are operated by a three-throw crank worked by a three-cylindered engine, the

motive power being supplied from the road-roller boiler by means of steam pipes and flexible tubing. In addition to the three-throw crank the machine is provided with a fly-wheel, stop-valve, and governor to regulate the speed of the machine when working. The raising or lowering of the machine is accomplished by means of rack-and-pinion gearing, the regulating of the depth of cut being quickly manipulated by a handle attached to a pinion, which can be locked by means of a lever. The action of the pecks causes the stones to be violently thrown about, so that to avoid damage arising from this cause it is necessary to enclose the lower part of the machine.

It is stated that this scarifying machine can loosen between 300 and 400 square yards of macadam in an hour, the condition of the surface of the road, wet or dry, making no difference in the amount of work done.*

321. Henderson's Machine for breaking up macadam.—This machine is the invention of the surveyor to the Kingston Highway Board, Surrey, and consists of a strongly-built iron frame triangular in plan. Two road wheels at the rear end and one at the front end of the apex carry the frame-work, which has an arrangement fixed in front for attaching it to a special drawbar on the tender of the road-roller. The perforating teeth or drills, nine in number, have a rotary motion; for this purpose each chuck-end or socket of the tool holder is fitted with a bevel wheel carried in proper bearings in a cross girder. These bevel wheels actuate a similar number of bevel wheels or mitre gears keyed on to a horizontal shaft revolving in suitable bearings fixed at each side of frame. The shaft is driven by toothed wheels, and a pulley on the shaft of the upper one connects with and receives motion through the driving-belt working on the fly-wheel of the road-roller; the mechanism can also be driven by shafting.

The depth to which the drills work is regulated by two men by means of side screws, which can be adjusted so as to suit the contour of the road at the haunches or channels. This machine weighs $2\frac{1}{2}$ tons, and nine drills are in operation when the scarifier or road-breaker is working at its full capacity, covering a width of 6 feet. The number of drills, generally three or four, made use of at one time, however, depends on the power of the engine employed to operate the machine and the hardness of the surface of the road, while the work is greatly facilitated by thoroughly watering the macadam previous to commencing scarifying operations.

This machine can only work in one direction; the road-roller, however, need not be uncoupled, as the engine simply pushes the scarifier backwards into the position for commencing another cut. It is stated that, when all the drills are in operation, it can break up a mile of ordinary road composed of

* Paper on "Machinery as adapted to the breaking up of Macadam," read at a meeting of the Incorporated Association of Municipal and County Engineers at Reading, by A. G. Collins, A.M.I.C.E.

flint macadam in one day or an average of 600 square yards per hour when an engine sufficiently powerful is employed, the cost working out at about ½d. per square yard. A 10-ton roller is not sufficiently powerful to work this machine when all the drills are made use of, so that it is usual to employ four drills in granite and six drills in flint macadam roads.

322. **Fowler's Machine (Eversbed's Patent).**—This machine is on the principle adopted in land cultivation by steam. The frame is mounted on road wheels, and has depth-regulating and steering-gear; the cutting tools are triangular in shape, and are retained in the sockets by locking screws. The number of teeth may be varied according to the condition of the road, the width scarified at one operation being 3 feet when the full complement of teeth are used. The wire rope, one end of which is attached to the engine, passes round a horizontal pulley of large diameter placed on the top of the machine, the other end being attached to a claw anchor fixed at the side of the road. A length of 40 lineal yards can be scarified at one time; then it is compulsory to stop the work and refix the anchor before commencing another stretch of similar length.

323. **Morrison's Scarifier.**—This machine is manufactured by Messrs. Aveling & Porter, Rochester, and is fitted to their road-rollers and traction-engines. The principal features of this scarifier are handiness, utility, and economy in the working expenses. The different parts of this machine are shown in figs. 112 and 113, the former illustration being a side elevation of the scarifier, attached by plates to the rear or tender end of a road-roller, and placed immediately behind the off-side driving-wheel.

The fixed frame *a*, containing the mechanism, is made up of channel irons, angle irons, and plates riveted together; it measures 33 inches by 28 inches by 12 inches, and is fixed to the rear of the tender by means of two steel plates, *b* and *c*, which latter extends to and is embraced by the horn plate close to the firebox, the lower end being stayed to the cross-bar at the rear end of the tender as shown. The outside part is braced by means of a heavy channel-iron connecting piece *d*, which is bolted to the lower end of the fixed frame *a*, and connected to the main axle of the driving-wheel by means of a cap bolted on to the boss of the nave *e*; it is further secured in position by an angle iron brace *f*, bolted to the connecting bar *d* and the top of the frame *a*. This constitutes the shell, or frame, in which the mechanism of the scarifier proper works, and it is evident that the whole apparatus is securely held in position by the arrangement described.

The inner framework comprises the steel rocking block *g*, working on a shaft which carries the double set of scarifying tools, or tines, *h*, secured in sockets by wedge keys. A set of tines, three in number, is placed on each side of the rocking block or 'tool box,' so that they are alternately brought into action when going backwards or forward.

The tool-holder is rocked over by a lever *i*, working in a curved slotted

bar *j* fixed to the inside frame, and locked in position by means of a screw *k*. A saddle or stop block *l*, at the lower end of the inside frame *a*, admits of the tool-block being firmly held in position either when the rocking lever

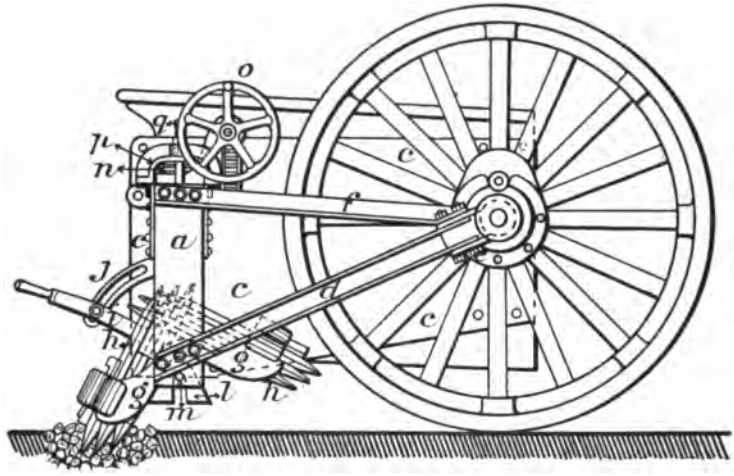


FIG. 112.—Morison's scarifier (side elevation).

is locked while scarifying in a forward direction or when the change of motion is reversed. It will be seen that while the lever is in its proper

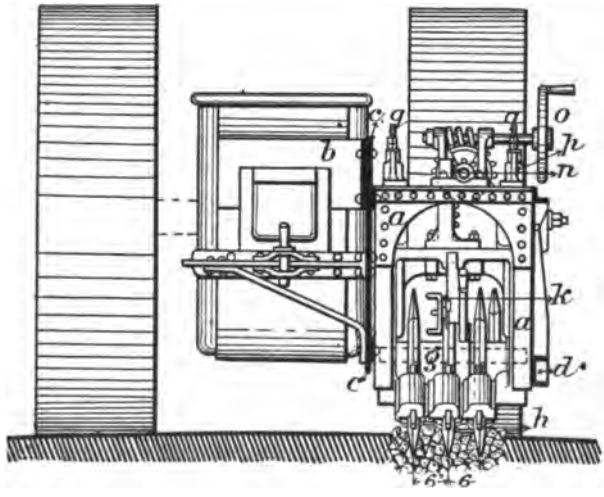


FIG. 113.—Morison's scarifier (end elevation).

position for scarifying, the rocking block fits closely on the saddle, securing it in a rigid manner, and also retaining the tools or tines at the proper angle when in operation. The through or stop-block bolt *m* prevents the saddle

being lowered too far, and at the same time acts as a distance piece, keeping the shell or outer frame in its proper position. The means for raising or lowering the rocking block or tool-holder is provided for at the top of the frame, and consists of a rack and pinion *n*, operated through a quick-acting worm-wheel and worm, which is controlled by the depth-regulating hand-wheel *o*.

A cast steel bridge, *p*, is fixed on either side on the top of the frame through which tension rods *q* pass, secured at the top by nuts, and placed in a vertical recess in the inside frame reaching to the rocking block shaft. Around these bolts is a strong spiral spring which minimizes, when working, any sudden shocks or vibration that may be transmitted to the engine.

The inner frame, made of cast steel, and comprising the saddle rocking block, lever, and rack arrangement, is held in position by the channel irons at each side forming the outer frame, and which also act as guides when the scarifier proper is being raised or lowered during the progress of the work. This machine works in either direction by an alternate pull-and-push movement, and its merits may be briefly stated as follows.

Being permanently attached to the road-roller in a convenient manner it is always available for use, and can be utilized in executing small repairs, or patching, as well as for continuous work. It can be operated equally well in either direction, and may be run close up to the side of channels, kerbs, or sod borders without the roller wheels passing over them. It is simple in construction, there being no complicated gearing to get out of order. It is a very effective machine, and performs its work thoroughly, expeditiously, and economically, the weight of the machine being only 11 cwts. The amount of work which can be accomplished by the aid of this machine and the cost of operating it will be given in detail later on in this chapter.

324. Rutty's 1896 scarifier was designed for carrying out light repairs, such as patching the centre of a road, for which purpose it is very well adapted. Being fixed immediately behind the tender of the engine or roller it cannot be brought into operation close to the side channels of a road or carriage-way, consequently it can only be utilized to a limited extent.

325. Burrell and Rutty's Road-breaking Machine.—This patent scarifier is intended to be permanently attached to the driving-wheel of a road-roller or traction-engine. The design is so arranged that when the scarifying tools are in operation, the engine always exerts a pulling movement, when travelling in either direction (which is a distinctive feature), instead of an alternate pull-and-push motion characteristic of scarifiers of the permanently fixed type. By this arrangement the necessity of the roller wheel passing over the newly scarified surface when working backwards is avoided. The machine consists of a triangular frame, rocking on the main axle of the engine. The rocking of the frame and the regulation of the depth to which the tines penetrate the macadam are controlled by suitable devices,

either by hand, by steam, or by an hydraulic arrangement from the foot-plate.

326. Fowler's (Fowler and Benstead) Scarifier.—This machine consists of a light triangular frame fixed on the main axle of the off-side driving-wheel of a roller or traction-engine. At the extreme points of the frame the tines or tools are fixed, the depth to which they penetrate being regulated by a screw. There are pivoted extensions at either end of the frame, carrying rollers or wheels which regulate, at either end alternately, the approximate position of the scarifier, and also for carrying auxiliary tines or spikes for loosening the macadam; strong cushioning springs are provided for the screw-regulating arrangement and on the extension pieces, admitting of a slight movement of the small wheels when in a vertical position.

327. Marshall's Scarifier.—This machine consists of a framework fixed at the rear of the engine, and extending the full width of the driving-wheels. The guides are fixed on this framework or bed plate, which admit of a saddle-piece or bracket being moved by means of a handle and screw in a horizontal plane or in a transverse direction. The saddle-pieces have spindles or trunnions at their lower end, which carry the swinging-frame containing the tines or tools, and which are capable of being rotated to a certain extent or of being held in position by fixed studs, depending on the direction in which the engine is travelling.

The swinging-frame can be locked in any desired position by means of a bolt working through a slot; the depth to be scarified being regulated by a handle and wheel working a worm and toothed quadrant.

As may be gathered from the foregoing description, the swinging-frame carrying the scarifying tools can be adjusted transversely to any position in the width of the engine.

328. Bomford's Scarifier.—The characteristic feature of this scarifier, which is shown in fig. 114, is the introduction of strong spiral springs to obviate (as is claimed) any damage being done to the engine through vibration. The whole pull, when working the scarifier, is taken by the spring drawbar fixed on the off hind roller axle. There is a small regulating wheel on the main shaft of the scarifier, intended to assist in following the undulations, and to break up the higher parts of a road surface deeper than the hollows. It is constructed on the principle of a fixed or rigid machine, but has not the advantages of such, owing to the springs, which yield considerably when a hard piece of macadam is encountered. The working of the machine is under the entire control of the driver on the foot-plate by means of suitable levers. By such an arrangement it would appear that a considerable amount in working expenses could be saved, but when it is understood that this machine can only work in one direction, the saving gained by only one man working the engine and scarifier is lost on account of the machine having to travel back without doing any work, or by reason of its having to

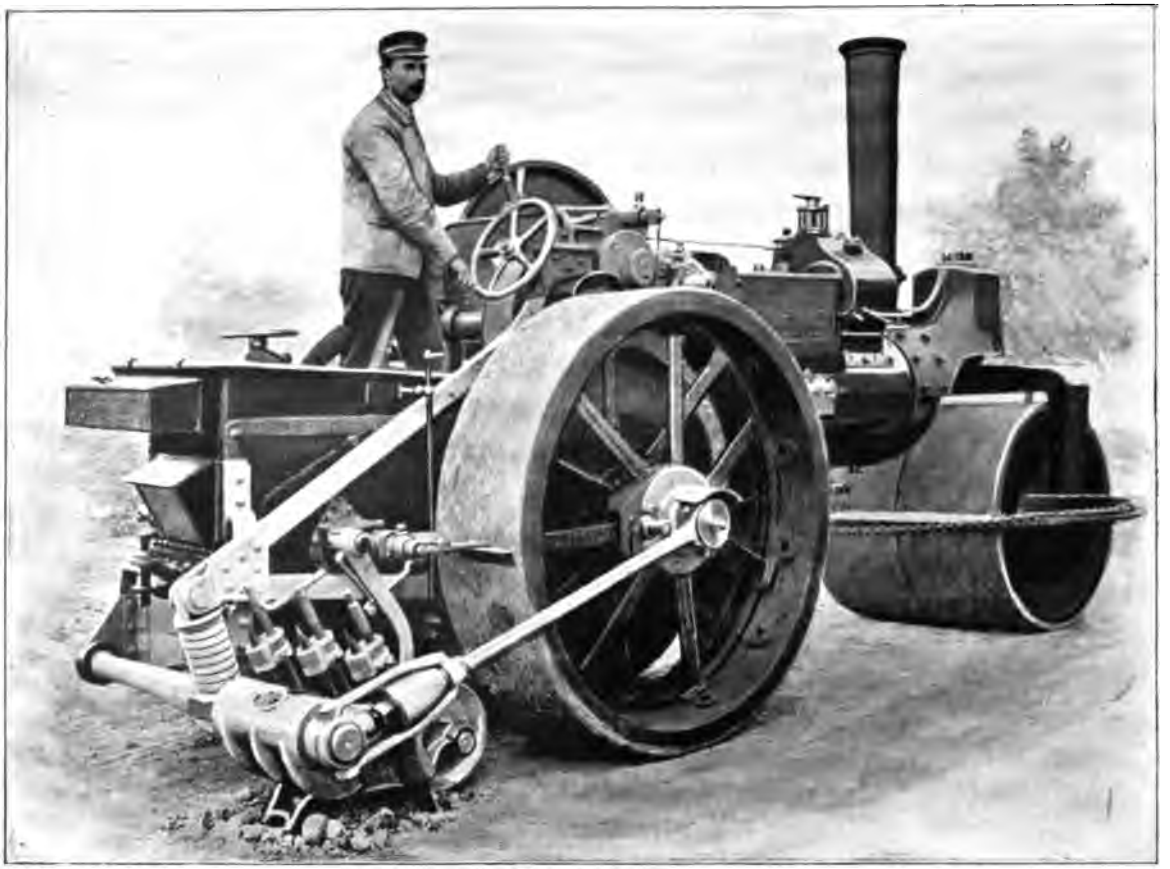


FIG. 114.—Bomford's spring scarifier. [*To face p. 240.*

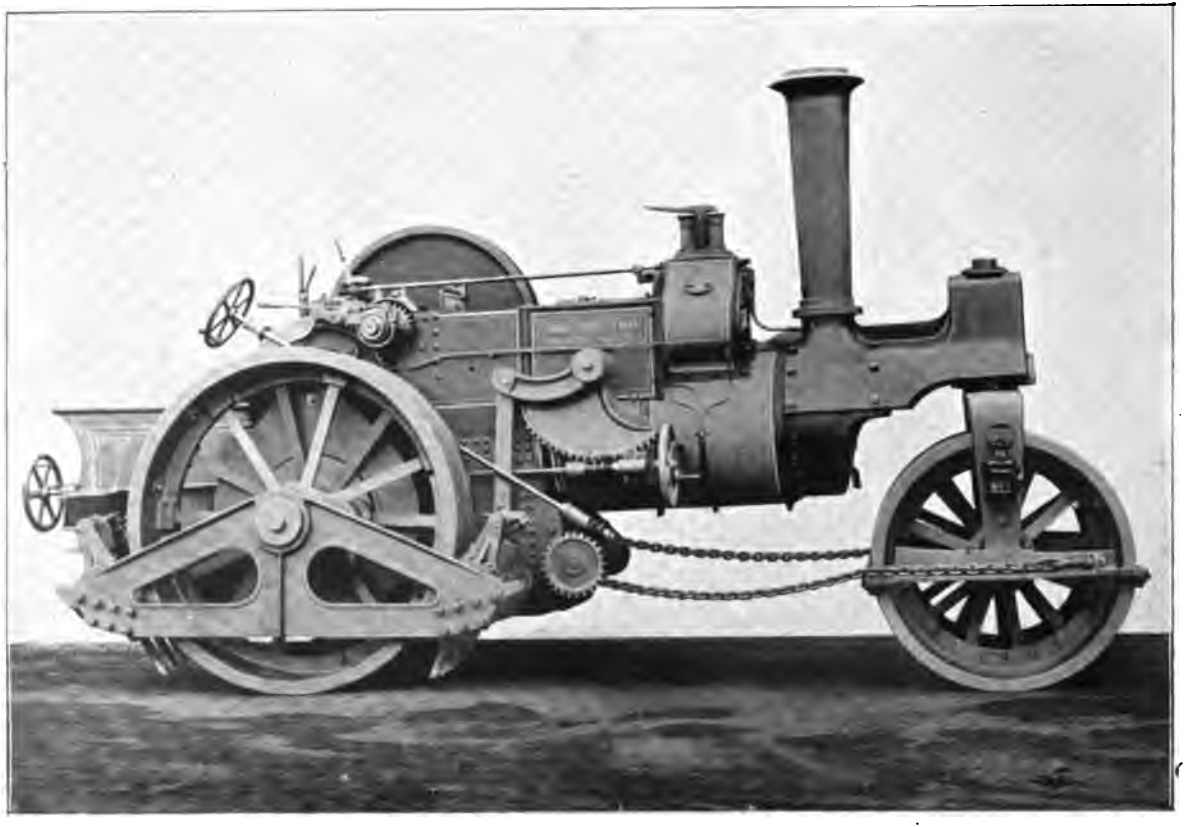


FIG. 115.—Hosack's scarifying machine attached to one of Burrell's road-rollers. [*To face p. 241.*

be turned round to make a return cut. The cost of this machine is £70, and it can be fitted to any class of engine. This patented arrangement is now the property of Messrs. Eddison and De Mattos, Dorchester.

329. Hosack's Scarifier.—This machine, made by Messrs. Burrell & Sons, is very similar to the scarifier (already mentioned) patented by Rutty & Burrell in 1897. It consists of a heavy triangular frame or bracket pivoted on the driving axle of the off-wheel. The sets of tines or tools are fitted at each end of the frame. The machine can be worked in either direction, the force exerted being always a pull. No matter in which direction the engine travels, it performs the scarifying in such a manner that the surface already lifted is not compressed again by the engine wheels in making a fresh cut immediately adjoining the loosened portion. In this particular Hosack's scarifier is a perfect machine. The depth-regulating arrangements are, however, somewhat complicated, the method of operating this part of the mechanism being as follows:—A lever attached to the end of the rocking-frame in front of the driving-wheel of the engine is connected with a toothed quadrant fixed on the boiler barrel, and is operated by a worm and wheel. The leverage is considerable, and liable to impart a large amount of strain on the working parts. A connecting rod with another wheel at the rear end of the engine works the depth-regulating apparatus when the machine is being moved in a forward direction. These regulating wheels are placed so far away from the outside line of the machine that the man operating it cannot properly see the surface of the road which is being scarified.

This does not materially affect the actual depth penetrated by the tines, as the driving-wheel, owing to the position occupied by the teeth following close to them, acts in a measure as a guide. In working, however, where numerous manhole covers, tobies, and such obstructions exist, the difficulties in operating it are greatly increased.

This machine weighs about 50 cwts., which is rather a heavy additional weight on one side of the roller when consolidating metalling; for an 18-inch wheel it is equal to about $2\frac{3}{4}$ cwts. per inch of width of rolling surface. The cost of this machine is £115, and it is illustrated in fig. 113, where it is shown attached to a road-roller.

330. A considerable amount of crushing of the metalling takes place when the engine on its return makes a cut parallel with that already accomplished. This is caused by the stones being raised and spread by the inner tine over the edge of the hard portion of the road, especially when penetrating to a depth of 4 to 5 inches. This crushing is obviated by three or four men following the machine, and raking the material, deposited on the solid road, over on to the loosened portion. A much more effective, and, at the same time, more economical method, is to attach a trailing plate of heavy iron fixed at an angle so as to remove any stones deposited on the un-

broken portion of the road, clear of the position of the wheel when making the next cut.

331. The last four scarifiers have been so recently introduced, and so little worked, that no authentic information can be given as to the actual cost of their working, reparation, and efficient maintenance.

332. Road-rollers are generally supplied with spikes, which can be fitted into the rim of the driving-wheels, for the purpose of loosening the macadam. They, however, cause considerable vibration and strain on the engine, without being efficient for the purpose intended. In America the ordinary agricultural plough, with a special arrangement of sockets or shoes, is made use of for scarifying macadam roads, and for breaking up pavements, four to eight horses being employed to operate it. The principal makers of this type of scarifier are the Syracuse Chilled Plough Company, New York.

333. From the foregoing description of the various types of scarifying machines in use, it will be seen that all accomplish a considerable amount of work proportionate to the power of the engine employed, so that the only ground for choosing one in preference to another is its handiness and economy in working.

It is obvious that for working purposes the preference should be given to the machine best adapted to the rollers in actual use, as there would be no saving in procuring a traction or road-engine simply to work the scarifier. For repairing or improving county roads, it is evident that the type of machine operated by means of a trailing movement, occupies a considerable extent of roadway, and necessitates in some instances the employment of additional hands to work the scarifier and assist in conducting the vehicular traffic past the machine.

Another weak point in connection with detached scarifiers working on county roads is the necessity of removing the apparatus to some convenient point, entirely clear of the roadway, when the operations for the time being are finished, unless the road is a very wide and quiet one. This constant removal to and fro may constitute a great drawback to their use.

These remarks, however, do not apply to the same extent in the case of suburban and town roads, as refuges in the form of depôts or workshops belonging to the authorities are generally near at hand. Of course these adverse conditions to the employment of trailing scarifiers are entirely removed when the road is given over exclusively to the operations on hand.

The question is which machine will perform the work most efficiently and economically, or what is the class of engine available consistent with the conditions already stated. A scarifying machine, no matter of what type, which requires the surface of the road to be previously watered so as to successfully operate it, entails an additional cost in the working expenses, which may be considerable if the available source of supply is at a distance.

A scarifying machine should be preferred which neither forms ridges nor violently displaces the stones when working, as considerable inconvenience and possible danger is thereby incurred. The practical benefits resulting from the employment of a macadam scarifying machine are numerous and important, and as an instance the following may be mentioned as occurring frequently in practice. Many badly shaped roads on which there is a considerable amount of serviceable metalling can be broken up by the aid of a scarifier and re-formed at a trifling cost, which improvement could not possibly be economically undertaken if hand picking had to be adopted. By re-forming the road surface after scarifying, the material may, in many instances, be rolled without any additional metalling being applied.

334. Hand Picking or Manual Labour.—Hand picking or manual labour, besides being an expensive operation, demands the employment of a large number of men to loosen the old surface of the road so as to ensure a sufficient amount of work being prepared to keep a road-roller steadily at work. This is not attainable in many districts, recourse being had, under the circumstances, to repairing a road with heavy coatings of metal, when refacing the surface was perhaps all that was necessary.

335. Cost of Scarifying by Hand Labour.—The cost of scarifying or picking by manual labour varies considerably, and depends on the nature of the macadam operated on, and its condition at the time.

Soaking the crust of the road with water adds considerably to the ease with which it can be picked. The greasy and sodden state of the detritus resulting from this, however, entails a considerable amount of after-labour, and if the old material is to be screened, the process of watering is decidedly objectionable, as it retards rather than aids the operations as a whole.

Under the most favourable circumstances, that is, when the metalling of the surface of a road contains a large proportion of soft material, the cost, including repairs to tools, etc., may only amount to 1·25d. per square yard, while, if the road surface is composed of very hard and compact material, the cost may reach 2d. or 2·25d. per square yard. This is at the rate of about 33 square yards per day in the former case, and 20 square yards in the latter for each man.

In attempting to scarify a road which has been steam-rolled by manual labour, the increased cost for re-sharpening and repairs to the hand picks are relatively high, while the area which a man can accomplish in one day may be reduced to 12 or 15 square yards; under these circumstances the cost of hand picking is from 3d. to 3·5d. per square yard, an amount which would suffice for spreading a coat of metalling on the road one stone thick, when the price delivered on the road is 6s. per ton. Besides being an expensive operation, the danger arising through the stones being projected by hand picking is considerable, and damage is likely to result.

In the author's experience an inclusive price of 1·75d. per square yard for hand picking is an average cost, on macadam composed of hard siliceous whinstone and basalt, when workmen's wages are at the rate of 4½d. per hour.

336. Amount of Work accomplished by Rutty's Scarifier. — The amount of work which can be performed by Rutty's improved scarifier depends very much on the hauling power of the engine employed, the nature of the metalling composing the crust of the road, and whether the surface is very hard and dry or in a moist condition. The interruptions from passing traffic also form a considerable item in the actual performance of the machine. It is stated that the machine is capable of thoroughly scarifying 300 square yards of hard macadam, 4 inches deep, in an hour under favourable conditions; but 150 to 200 square yards is considered good work when the exigencies of the traffic preclude continuous working, and an ordinary traction-engine or roller is employed.

337. Cost of Scarifying with Rutty's Machine.—The cost of scarifying in country districts, under favourable conditions, will, therefore, allowing for hire of engine and wear and tear of the plant and the sharpening of tools, be 0·12d. or one-eighth of a penny per square yard. When the passing traffic is such that considerable delays are experienced, then the cost will be increased to 0·62d. or three-fifths of a penny per square yard. In large towns where the cost of labour, fuel, and the hire of engines are considerably higher than obtains in rural districts, the cost must necessarily be greater, amounting to 0·5d. and in some cases to 1d. per square yard.

The author has seen Rutty's improved scarifier, working in Hyde Park, London, effectively loosen macadam at the rate of over 400 square yards per hour, the roadway being given over to its exclusive use. Allowing for the higher cost of labour and collateral expenses, compared with that generally paid in country districts, the amount of the working expenses would be increased by 0·15d., which gives a total of 0·77d. per square yard, exclusive of repairs, depreciation on engine, and the time lost in bringing the plant to and removing it from the ground. Each set of tines, three in number, will scarify 150 square yards before requiring to be re-sharpened; the cost of dressing and tempering each tine is 3d., which is equal to 0·06d. per square yard or $\frac{1}{16}$ of 1d. The firm of Messrs. G. G. Rutty & Co. let out their scarifiers on hire, charging a royalty of ½d. per square yard of macadam loosened; they also supply the motive power and all tools necessary at an inclusive cost of 1d. per square yard; but when the old material of the roadway is re-formed for the new coat of metalling, the charge is on an average 1½d. per square yard.

This machine has hitherto been exclusively used in scarifying the Victoria Embankment (about 60,000 square yards), for the London County Council, and also for the roads in the public parks for Her Majesty's

Commissioners, namely, Hyde Park, St. James's Park, and Kensington Gardens. A considerable number of these scarifying machines are, however, now used by different Councils and Local Boards.

338. Amount of Work done by Morrison's Scarifier.—The amount of work which can be performed by one of Morrison's patent scarifiers attached to an Aveling & Porter 15-ton road-roller (fig. 110) will now be detailed, along with the cost of working it, based on the author's experience, extending over a period of four years, during which time extensive scarifying operations in conjunction with steam road-rolling have been carried out. The scarifier has two sets of three tines or tools, which are used alternately, so that the machine can work in either direction. The tools or tines are made of square bar steel, with tapered points at both ends, as already mentioned, and can be regulated to penetrate and loosen uniformly to a depth of from 2 to 4½ inches, which for most purposes is considered sufficiently deep. The tines or teeth are spaced at 6 inch centres, being sufficiently close to effectively break up the crust of a road, while the loose material is left in a regular manner, causing little or no inconvenience to passing traffic. Scarifying machines which have the teeth wider apart are apt to leave a certain portion of the road surface undistributed. In consequence of this a series of ridges and furrows is formed, which will greatly inconvenience the public traffic and increase the cost of the operation by making it necessary to level the old metalling to a proper contour, while the subsequent rolling is never satisfactory under these circumstances. The width of surface disturbed or loosened by Morrison's machine is 18 inches when the tools are penetrating the macadam to a depth of 4 inches; with a less depth the width of macadam broken up will be correspondingly decreased.

If the road is very narrow it is possible that the width of the roller will not admit of the whole surface being broken up by the machine; it will then be necessary to employ manual labour to complete the operation. Roads having such a narrow width are the exception.

It is the usual practice to commence scarifying at the sides of a road and gradually work towards the centre, when the roller has to be turned completely round in order to proceed with the other half of the macadam surface.

The minimum width of a roadway which a scarifier of this description, attached to a 15-ton roller, can operate on so as to effectively break up the whole of the macadam surface is 12 feet. A 10-ton roller fitted with one of these machines can easily scarify the whole surface of a road 10 feet in width.

Many circumstances arise which influence the amount of work performed each day, such as the narrowness of roads (as compared with wide ones), steep gradients, and the work having to be carried on during wet weather. The tines or scarifying tools, in each set of six points, when properly dressed

and tempered, will scarify on an average 786 square yards, and the cost for sharpening each tine or tool (two points) amounts on an average to 3d. and 3½d. each, or 1½d. to 1¾d. per point. This is at the rate of 0·013d. per square yard of road surface scarified, or $\frac{1}{77}$ of a penny. The following figures detailing the amount of work done and the cost of the operations, are based on an average depth scarified of 3 inches on roads the metalling of which extends to a width of from 16 to 20 feet and upwards, either when there is a considerable amount of wheel traffic causing interruptions to the progress of the work, or when the road is given over entirely to the repairs, compared with working on narrow roads under similar conditions.

The extent to which scarifying can be accomplished on a gradient is necessarily reduced considerably as compared with working on a level stretch of road. This is especially the case when the gradient exceeds 1 in 20, as the roller will then be capable of working the scarifier in one direction only, namely, down the incline.

When the surface of a road is damp the work of breaking up the surface is more easily accomplished so long as it is not so greasy as to cause slipping of the roller wheels. When the macadam is soaked with water, or when the operations are carried on during rain, it is advisable to work the machine in a forward direction only. This avoids compressing the already scarified old metalling, by the passage of the wheels of the roller over it when the return cut is made with the engine travelling backwards. When the material is in a comparatively dry state, the driving-wheels of the roller passing once over the newly scarified portion of the road does not compress it to such an extent as to prevent its being easily lifted or raked into proper shape.

On level roads of average width, and when the interruptions caused by wheel traffic are not numerous, this machine can break up in an efficient manner the surface of a macadamized road at the rate of 400 square yards per hour. On roads with moderate gradients and under similar conditions of traffic, the quantity of scarifying which can be accomplished in the same time amounts to 350 square yards.

On roads where the gradient exceeds 1 in 20, and up to the limit at which the roller can steam safely tender first, and also on level roads during continuously wet weather, which may necessitate the machine being operated in one direction only, the amount of work done will vary from 250 to 300 square yards per hour.

When the gradient exceeds this limit the area which can be scarified will depend on the facilities which exist for the speedy turning of the roller completely round at the commencement and end of each cut when scarifying one half of the road. Under such circumstances, and when the interruptions are not numerous, the amount of work which can be accomplished in an hour may be taken at from 200 to 250 square yards. These figures apply to

roads which had been previously steam-rolled, and are based on the average extent of scarifying performed under the varying conditions mentioned.

Allowing 25 per cent. for hilly roads and for roads having a considerable traffic, the average is 300 square yards per hour.

339. Cost of Working Morrison's Scarifier.—In the following table, XXXVI., the cost of watering the surface is not included in the working expenses, as, for reasons already given, the author does not approve of this method of carrying on the work in the majority of cases. The cost of a day's work of nine hours is made up of the following items:—

TABLE XXXVI.

	Cost per day. s.	d.
Engineman,	4	0
Scarifier attendant,	3	6
Flagman,	3	0
Coals for engine (steam navigation), including carting, 5 cwt., 12s. per ton, oil and waste 8d.,	3	8
Team work, water-cart for supplying engine; as it is only required occasionally, allow 50 per cent. on a day's hire at 8s.,	4	0
Sharpening scarifier tools,	3	0
Depreciation and repairs on roller and scarifying machine,	2	6
	23	8

When the source of the water-supply is conveniently situated the water-cart is not required, but when it is situated at a considerable distance the exclusive services of a man and horse may be necessary. For 2700 square yards per day this gives a rate of 0·101d., or slightly over $\frac{1}{10}$ of a penny per square yard of surface scarified.

The greatest area which has been loosened by Morrison's scarifier under the author's directions was 650 square yards per hour 3 inches deep, at a cost of $\frac{1}{14}$ part of a penny per square yard on a road which had been rolled seven years previously. This is an exceptional performance, as the work was carried out on a road where few interruptions occurred The cost of operating this machine in some of the English districts where they have been adopted has averaged about $\frac{1}{8}$d. per square yard. This is slightly in excess of the price stated above, but may be accounted for by the higher wages paid, the greater cost of fuel, and the increased collateral expenses. A scarifier attached to an engine on the principle described in the foregoing paragraphs is capable of performing a sufficient amount of work in one hour to keep a road-roller at work for five hours consolidating a new coat of metalling spread over the scarified portion. In other words, from $1\frac{1}{2}$ to 2 hours occupied in scarifying will be sufficient when continuous coatings of metal are applied for one day's rolling.

340. This machine, which is of quite recent introduction, is being adopted extensively where the benefits of scarifying are properly understood and appreciated. Being constructed in a handy form it is easily and quickly manipulated, while the space occupied by the machine is not an inconvenience when the roller is engaged on either town or country roads in the ordinary work of consolidating the metal coatings. There are about three hundred of these machines in use at the present time.

341. Cost of Scarifying by Hand and Machine Compared.—Scarifying by hand labour or stocking, even when average workmen are employed, is far inferior to a modern mechanical macadam scarifier as regards economy in time and cost. On an average one man will pick from 25 to 30 square yards, $2\frac{1}{2}$ inches deep, in a day of nine hours, at a cost of $1\frac{1}{2}$d. to $1\frac{3}{4}$d. per square yard, which includes the charge for sharpening picks and for repairs. A scarifying machine will do as much work as one hundred men can do in the same time. The saving effected by using a macadam scarifier, inclusive of all charges, over that performed by manual labour, may, under ordinary circumstances, be estimated at 94 per cent.

CHAPTER VIII.

THE CONSTRUCTION OF NEW AND THE MAINTENANCE OF EXISTING ROADS.

342. In a preceding chapter full details have been given, especially of the methods adopted in selecting the most suitable line in laying out a new road and the manner in which the construction is carried out, embracing the earthworks, drainage, and bridges.

The methods employed in quarrying the material, reducing the rock to road metal, and its subsequent consolidation by steam rolling, have also been described in detail, the cost of each operation being taken from the results of practical experience.

343. The method of constructing a new road, by which is meant the part forming the bottoming and top metalling, and the maintenance of roads generally, as practised at the present time, will now be described. To make and maintain these in an efficient manner requires careful investigation and consideration.

Modern exigencies are such that machinery is employed almost exclusively in the construction and repairing of roads, and has to a considerable extent superseded the principles and methods adopted in road making by the two great pioneers, Telford and Macadam.

344. In the method followed by Telford (who was called upon to lay out new roads and improve the line and gradients of existing ones in different parts of the country) the type of foundation adopted depended on the local supply of suitable material. Telford's name is associated with the system of hand-set stones as a pavement foundation on which the top metal or wearing surface is placed. In the construction of many new roads, and the alteration of existing ones, where suitable material could not be obtained for a paved foundation, Telford used what could be procured locally, such as gravel or layers of chalk and gravel.

345. Telford's Specification of Roads.—The following specification of a 30-foot pitched foundation roadway was that adopted by Telford, and a similar form is occasionally employed at the present time when making new roads :—

"Upon the level bed prepared for the road materials a bottom course or layer of stones is to be set by hand in form of a close, firm pavement; the stones set in the middle of the road are to be 7 inches in depth; at 9 feet from the centre 5 inches; at 12 feet from the centre 4 inches; and at 15 feet 3 inches.

"They are to be set on their broadest edges lengthwise across the road, and the breadth of the upper part of the said pavement is to be broken off by the hammer, and all the interstices to be filled with stone chips firmly wedged or packed by hand with a light hammer, so that when the whole pavement is finished there shall be a convexity of 4 inches in the breadth of 15 feet from the centre.

"The middle 18 feet of pavement is to be coated with hard stones to a depth of 6 inches. Four of these 6 inches to be first put on and worked in by carriages and horses, care being taken to rake in the ruts until the surface becomes firm and consolidated, after which the remaining 2 inches are to be put on.

"The whole of the stone is to be broken into pieces as nearly cubical as possible, so that the largest piece in its longest dimensions may pass through a ring $2\frac{1}{2}$ inches inside diameter.

"The paved spaces on each side of the 18 middle feet are to be coated with broken stones or well-cleaned stony gravel up to the footpath or other boundary of the road so as to make the whole convexity of the road 6 inches from the centre to the sides of it, and the whole of the materials are to be covered with a binding of $1\frac{1}{2}$ inch of good gravel free from clay or earth."*

A cross-section of Telford's roads as specified above is shown in fig. 116.

It has been already observed that Telford did not always make use of a pitched foundation, but employed such material as gravel, which was applied

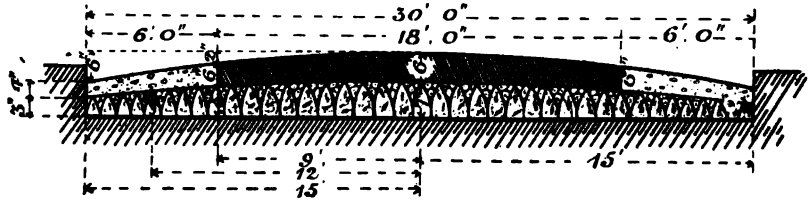


FIG. 116.—Cross-section of a 80-foot road (Telford's).

on parts of the road between London and Shrewsbury, while this class of bottoming was utilized in many of the new roads constructed by him.

It was the complete separation of the road metalling from the subsoil that Telford aimed at in adopting a pitched foundation, in order to prevent the useful wearing material coming into contact with the natural soil. He also recommended, when the drainage was difficult to effect, that gravel,

* *A Treatise on Roads*, by Sir Henry Parnell.

sand, vegetable soil, and chalk should be used, but he generally advised the adoption of the former method when suitable material could be conveniently procured.

346. Macadam's System.—Macadam's system differed materially from that of Telford, but both Macadam and Telford insisted on the necessity of thorough drainage of the formation or bed of the road and subsoil, which had prior to that time been entirely neglected in road making.

Macadam was satisfied with laying the metalling directly on the surface of the ground, after the irregularities had been levelled and side ditches formed; or, in other words, he preferred to build up the road above the surface of the ground.

The method of construction (common previous to Macadam's time, and practised in many instances during recent years), that of cutting a trench or 'box' sufficiently deep to retain the road material—was condemned by Macadam as detrimental to efficient drainage.

He contended that the use of metal broken to a small cubical size, which would unite by their own angles into a compact impervious covering, ranging in thickness from 5 to 9 inches, combined with perfect subsoil drainage, was sufficient for any class of traffic.

To Macadam is due the credit of having been the first to direct public attention to the great necessity of properly breaking the material to a uniform size and cubical form, ranging from $1\frac{1}{2}$ to 2 inches, and weighing less than 6 oz. He was instrumental also in bringing the management of the highways into a regular system under qualified surveyors.

The services of Macadam and his staff of assistants were in great demand over a considerable part of Britain at the beginning of the present century.

347. Advantages and Defects of Macadam's and Telford's Methods of Construction.—Of the two systems much can be said, especially when they are severally applied to the varying conditions and nature of the different soils met with in practice.

A paved foundation, to be of any advantage, requires to be very carefully executed with the best possible class of materials; even then there may be a large number of unfilled spaces (inseparable from this method of construction), which sometimes act as drains, so as to allow the water to reach and to soften the natural soil; the repetition of this process moves the foundation and destroys the cohesion of the wearing part of the road. Defective drainage, even of a temporary nature, will cause this; the subsoil gradually working upwards is mixed with the metalling, while the latter is pressed down into the bottoming of the road. A road formed entirely of broken stones and consolidated by wheel traffic does not present any voids, but as the interstices are composed to a large extent of soft material, more especially at the lower part resting on the subsoil, the crust of the road is liable to suffer if situated on a damp subsoil of a retentive nature.

The bottoming of a road is sometimes carried out in an indiscriminate manner, and the so-called 'pitched pavement' is often made with no better material than that obtained from old buildings in the form of freestone, bricks, and lime rubbish tipped on the formation level of the road in a promiscuous manner, and roughly graded to the required contour.

A system of construction combining the two methods mentioned may be adopted in general practice with great advantage. A bottoming of stones about one-third of the size adopted for a pitched foundation, and consequently two to three times larger than ordinary macadam, spread to a sufficient thickness, then covered with a coating of ordinary road metal consolidated separately by steam rolling, has been attended with beneficial results. By adopting this method of making roads the cost of construction is reduced compared with the expensive methods inseparable from the different systems carried out by Telford and Macadam.

348. The great advance in the use of mechanical appliances in road construction and maintenance has made possible what could not hitherto have been accomplished, not only from a practical point of view, but by reason of the greater efficiency and economy attained.

Previous to entering into the details of the construction of roads it will be necessary to consider the nature of the soil or bed on which the proposed road will rest.

The preliminary work of grading and forming the cuttings and embankments described in the previous chapter which treated of the work necessary to be accomplished in general. The nature of the ground on which the road is to be placed demands attention, however, and apart from the under drainage therein treated, the several kinds of soil composing the strata necessarily require different treatment.

349. The Effects of Sub-soils on the Methods of Construction adopted.—In constructing a new road over sand or gravel (the simplest case met with in practice), it is quite unnecessary to adopt a pitched foundation. On the other hand, if the road bed is a retentive clay, the spreading of metalling directly on the soil, according to Macadam's principle, would be a failure.

In the first case the natural drainage cannot be improved upon, and consequently an expensive pitched foundation can be dispensed with, while the system advocated by Macadam would be applicable.

On a road bed, the soil of which is of an argillaceous nature, subsoil drainage can only partially relieve the general surface on which the road materials are to be placed. Under these circumstances it would be inadvisable to set a pitched foundation directly on such a surface, as in the event of the subsoil drainage becoming temporarily inoperative, or should the material composing the crust of the road be disintegrated by the alternate action of frost and thaw resulting in the metalling being made permeable,

the road bed would be liable to saturation with water in rainy weather. The clay would then gradually rise between the paved foundation stones by reason of the pressure exerted by the wheel traffic pressing the metalling downwards. By such a process considerable injury to the macadam of the road would result, while the incorporation of an undue amount of soft material in the road coating must necessarily, sooner or later, deteriorate and possibly destroy it.

A road constructed on Macadam's principle would likewise suffer, probably to a greater extent, by being placed on a clay bed under similar conditions. In such circumstances it is advisable to apply a suitable material to entirely separate the soil from the road material. This is readily accomplished by spreading a layer of furnace ashes, sand, or other material of a similar nature from 3 to 6 inches thick over the surface. This at once forms a cushion to receive and thoroughly separate the road material from the soil, while at the same time this intermediate layer admits of perfect under drainage. It may be an expensive means of efficiently carrying out the work when suitable material cannot be procured locally, but economical maintenance can only be looked for by adopting approved methods of construction.

Too many roads, unfortunately, have been constructed without such precautions being taken, with results which are not only apparent from the relatively high cost of maintenance, but also from the surface requiring almost constant attention and repairs, while the necessity for scraping and the removing of mud during wet weather is greatly increased.

It is advisable when the road is formed in rock cuttings to spread a layer of sand or other material of a light nature, so as to fill up the irregularities of the surface, and that will also form a cushion for the road materials to rest on. Should the bottoming be placed on a hard surface, as in the case of rock, the material is apt to be pounded and destroyed during the process of consolidation.

350. The practice of thoroughly consolidating the ground when forming new roads by means of a light roller previous to commencing the actual structure, has much to recommend it. This operation should be carried out in dry weather, and any depressions on the surface that may be caused by the passage of the roller should be made good with the same class of material as the surrounding soil. The process of rolling must be repeated until a uniform and solid bed is obtained which will enable the surface of the ground to sustain the superstructure, and the weights brought upon it.

351. Method of Construction adopted at the present time. — A system of bottoming roads combining the methods practised by Telford and Macadam, has long been adopted by engineers and surveyors. It consists in spreading the metalling on a layer of 3- or 4-inch cube stones from 6 to 12 inches thick. The advent of the steam roller has materially aided this form

of construction, the practical and economical benefits of which show that this method may be looked upon as almost perfect for macadamized roads.

The first points to be considered are the width of the proposed road and the amount of contour or convexity required for adequately draining its surface.

352. Width of Roads.—The width of a new road will be determined by the prospective wheel traffic.

It is a common practice to make a road sufficiently wide to allow of two or more vehicles passing each other easily when travelling fast. For ordinary road traffic 12 feet of metalling will be sufficient, but this may be increased to 20, 25, 30, and 35 feet according to circumstances; but in any case it must be adapted to the probable amount of wheel traffic.

An unnecessarily wide road will cost more in proportion to maintain than one which is of the proper width, while the first cost of construction is, so far, practically thrown away. If a wide road is not kept in good order it assumes a very untidy appearance. A narrow road, on the other hand, is generally very difficult and expensive to maintain.

In most cases roads are made narrow, because the amount of money available will not suffice for making them wide; but there is no economy in making a road either narrower or wider than is required by the exigencies of the locality. When the requirements necessary to accommodate the traffic of future industries which may arise in a district cannot be determined with any degree of certainty, it is advisable to make provision for it in forming the earthworks. The road proper may be made to suit the existing requirements of the traffic, so that should necessity demand it the roadway can be widened at any future period.

The width of existing roads necessarily varies according to the geographical position which they occupy. An ordinary country road may, in view of its importance, be metalled to a width of from 10 to 15 feet, while a main road may vary from 15 to 25 feet.

Roads situated between large towns, and those in suburban districts, are usually 25 to 30 feet wide, while city roads generally have a width of from 30 to 45 feet. In many instances, however, 50 to 60 feet has been adopted in laying out new streets in the larger cities, while a width of 100 feet and over is proposed for some of the principal thoroughfares in the metropolis to relieve the congestion of vehicular traffic, which has been expanding to an enormous extent for many years past.

The widths stated do not include footpaths, which are usually provided on one side of the road, and in many instances on both sides, as in villages and populous places.

The footpaths generally occupy a width of 6 to 7 feet, so that on county main roads, exclusive of side verges, the total width of roadway may be

from 21 to 31 feet, while in the case of suburban roads, with footpaths on either side, the entire width is generally from 37 to 42 feet.

353. Contour of Roads and Minimum Gradients.—The cross-section which should be given to a road of certain width is a matter of great importance. It is usual to construct a road which is practically level longitudinally with more convexity or a greater contour, than one which has a minimum gradient of 1 in 80 to 1 in 100. The latter inclination will, even should the convexity of the road be inconsiderable, enable the surface water to be efficiently drained to the side channels.

The best form of cross-section to give, like many other details in connection with road work, is a matter about which a great diversity of opinion exists.

Macadam considered "that a road should be as flat as possible with regard to allowing the water to run off it at all, because a carriage ought to stand upright in travelling as much as possible." * The rise or versed sine given by Macadam was 3 inches on a width of 18 feet, his view being that, if the surface be well made and smooth, the water would run off freely with such a convexity.

Telford recommended the form to be that of a flat ellipse, the rise being 6 inches on a road 30 feet wide.

Many authorities have advocated a cross-section composed of straight lines falling towards the channels at an inclination of 1 in 24, and joined by a short curve at the crown of the road. By adopting this form of cross-section it is obvious that the contour will soon be destroyed by the inclined flat sides wearing into hollows between the crown of the road and the haunches. When the central portion of a road is worn flat, or there is a want of convexity, the surface rapidly becomes destroyed by the wearing effects of the traffic and defective drainage combined. The practice of giving an excessive contour to roads, or, as it is sometimes termed, making it 'hogbacked' or 'barrelled,' should be avoided, as it is with difficulty that vehicles can travel over them with safety except at the centre. A road having an excessive rise, besides being dangerous, either causes the wheel traffic to be confined to one track at the crown of the road, or when travelling on the sides the tendency of the wheels to slip or travel towards the channels creates a considerable amount of wear on the road surface.

It is evident, under these circumstances, that the labour of horses is greatly increased, while the wear to the wheels of vehicles is aggravated. The excessive contour which a curve at the crown of a road joined by two straight lines produces is shown in fig. 117, which also shows a flat ellipse for a similar width of road.

The best convexity for all practical purposes is a rise of from $\frac{1}{60}$ to $\frac{1}{40}$ of the width of the metalling. The form should be that of a flat elliptical curve, which, besides admitting of the greatest amount of wear to be

* *Parliamentary Report on the Highways of the Kingdom*, 1819, p. 22.

obtained from the metal coating, is sufficient to pass off the surface water freely.

The former rise gives a transverse gradient of 1 in 33 nearly, for three-fourths of the width of the roadway, and this convexity is made use of on suburban roads and those maintained on the patching system. The latter rise, namely, $\frac{1}{40}$ of the width of the metalled portion of the roadway, is

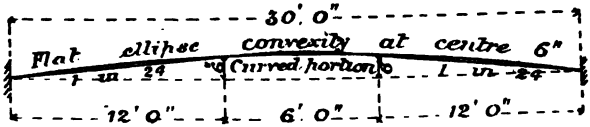


FIG. 117.—Elliptical and straight line and curve contour.

that invariably adopted when the metal coating is spread the full width and steam-rolled; it is a gradient nearly equivalent to 1 in 25 for a considerable breadth of the central portion of the road. This additional rise is necessary, because after a few years' wear, the general contour approaches that of the former, or 1 in 33, and that before the surface has to be refaced.

354. Details of Construction.—When the road bed has been prepared, a layer of stones varying in size from 3- to 4-inch cubes, and weighing from $1\frac{1}{4}$ to $1\frac{1}{2}$ lbs., is spread over the surface to the intended width, the thickness being regulated according to the class of road and the amount of traffic likely to pass over it. The bottoming material may be prepared in the quarries and subsequently conveyed to the works, or (as is generally the method adopted) the rough material is carted direct to the road under construction and deposited on the formation bed, when it is hand-broken and formed to the required width and thickness. Where the material for bottoming is broken in this manner the cost will be from 6d. to 8d. per ton (including spreading, but excluding the cost of quarrying and haulage).

A depth of from 6 to 9 inches for roads in country districts may be considered sufficient, the thickness being increased to 12 inches for suburban and town roads. The formation bed of county roads is generally made level transversely, the requisite contour being attained by increasing the thickness of the bottoming and metalling in the centre of the road. This, of course, presents a road the sides of which are not equal in strength to the central portion, but as from 50 to 75 per cent. of the wheel traffic on this class of roads passes along the middle part, the wear is there greatest and the flanks or bermes are relatively strong in proportion.

For suburban and town roads, or for exceedingly wide county roads, where the wheel traffic spreads entirely over the surface, and is therefore equally distributed upon the road, it is desirable to form the foundation of a uniform thickness and of equal strength. This is accomplished by making the formation bed of the road conform transversely to the contour which the

finished surface will assume when finished. Figs. 118 and 119 show a cross-section of a country road and that of a suburban road respectively.

The bottoming, whether for suburban or country roads, should in every case be steam-rolled, the interstices being filled with sand or gravel brushed into the joints during the final stages of consolidation. Artificial watering should not be permitted until the rolling is completed, when the work may be tested by sprinkling water over the surface to ascertain if the voids

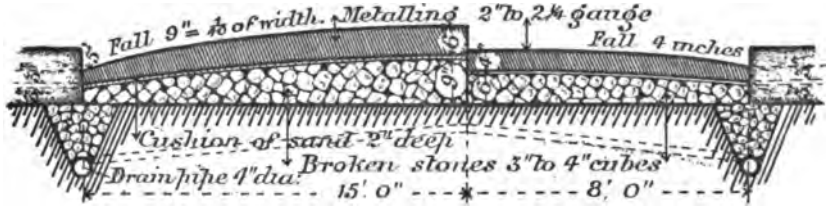

Fall 9" = ¼ of width
Metalling 2" to 2½ gauge
Fall 4 inches
Cushion of sand 2" deep
Drain pipe 4" dia.
Broken stones 3" to 4" cubes
15' 0"
8' 0"

FIG. 118.—Cross-section of a country road.

between the stones forming the bottoming are thoroughly filled. Great care is necessary, however, when applying water under these circumstances, as should an undue amount reach the bed of the road and soften the soil, depressions will be formed by subsequent rolling, which may possibly result in a permanently weak place being formed.

In the event of depressions being formed, resulting from the unequal capacity of the soil for bearing the material composing the bottoming, or by reason of water finding its way to the road bed or formation, it becomes

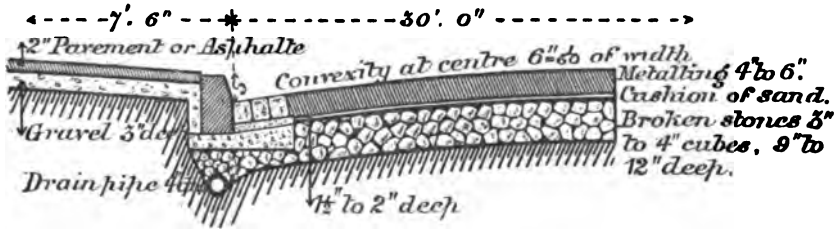

7' 6"
30' 0"
2" Pavement or Asphalte
Convexity at centre 6" to of width
Metalling 4" to 6"
Cushion of sand.
Broken stones 3" to 4" cubes, 9" to 12" deep.
Gravel 3" de
Drain pipe 4"
½" to 2" deep

FIG. 119.—Cross-section of a suburban road.

necessary to add more material of the same nature and quality, in small quantities, until the whole surface is brought to a regular and uniform contour.

On this foundation or pavement a cushion layer of sharp clean sand or fine gravel should be spread, from 1½ to 2 inches in thickness, to receive the top metalling. If this precaution is not taken, the metal coating, especially if it be of moderate thickness, will be crushed by the action of the roller wheels pressing the stones on the hard consolidated bottoming

The top metalling may now be proceeded with and spread to a thickness, according to the requirements considered necessary, but generally varying from 3 to 6 inches. If the latter thickness is necessary, it will be advisable to carry out the work by spreading the material in two layers and consolidating the first before applying the second coating.

355. In either case the rolling should be commenced at the water tables or outside edge of the metalling and be gradually extended towards the crown of the road. After repeated passages of the roller, and when the macadam has been properly set or interlocked, binding of a sandy description may be applied by shovels, care being taken to spread it evenly over the surface of the metal coating.

The rolling is continued meanwhile with the addition of an artificial supply of water and brushing, until all the interstices between the stones are filled up.

Great care must be exercised to prevent any unnecessary watering, which, besides doing no good to the metalling, might penetrate and do damage to the foundation by softening the natural soil. The surface is finished by applying a coating of screenings from the stone-breaker one-half inch thick, the roller passing backwards and forwards until a thoroughly solid and smooth surface is obtained, any surplus binding being swept off during the final stages of rolling.

356. Cost of Rolling Road Bottoming.—The cost of steam-rolling from 6 to 12 inches of bottoming and filling the voids with sand, assuming the latter has been obtained within a reasonable distance of the work, may be put down at 3d. or 4d. per ton of material consolidated. The consolidation of the top metalling in forming new roads requires a considerably longer time than does that of a coating of metal spread on an existing road. This may, in certain circumstances, amount to 1s. per ton of metalling consolidated, or an average of 8d. for the combined operation of rolling the bottoming and top metal when these quantities are of equal depth.

Maintenance of Macadamized Roads.—To maintain an existing road in good order it is necessary to perform the work either by annual repairs or by applying a wide and continuous coat of metalling and then steam-rolling it. Roads repaired by the latter method, depending on the quantity of metalling applied, may wear for a considerable number of years with but little attention.

357. Wear on Roads.—The wear of the macadam composing the crust of a road is due to two causes, namely, the traffic and the weather. The amount of the former, and the wearing effect due to wet weather and wheel traffic determine to a great extent the quantity of material necessary for the efficient maintenance of the surface of a road. Frost has the effect of expanding the moisture in the crust of a road in proportion to the amount of soft or muddy material which it contains. Alternating frost and thaw,

when the road contains a high proportion of detritus to hard material, break up and in many cases destroy the surface of roads, even when the thickness of metalling is ample to sustain the heaviest vehicular traffic in ordinary circumstances.

Sir J. Macneill estimated the wear due to atmospheric causes at 20 per cent. of the total; while of the 80 per cent. due to traffic, 60 per cent. was caused by the action of the horses' feet, and 20 per cent. was due to the wheels of fast coaches. In the case of heavy or waggon traffic, the wear caused by the feet of horses was stated to be 44½ per cent., and that by the wheels 35½ per cent. Any obstruction on, or irregularity of, a road surface increases the draught considerably, and the wear or injury caused by the action of the horses' feet is augmented accordingly.

It is obvious that on a hard smooth surface the combined wear caused by the action of horses' feet and the wheels of vehicles, especially in the case of heavy loads, is comparatively less than on a road the surface of which is uneven or of a yielding nature.

358. Repairs by Patching.—In patching a road the quantity of metalling which it is necessary to apply each year will have to be determined (as already pointed out) by the amount of wheel traffic passing over it, the quality of the macadam employed, the situation, whether shaded or open, and the facility with which the surface and subsoil drainage can be disposed of.

On practically level roads the consumption of material for repairs, compared with a similar length of road situated on a gradient of 1 in 80 or 1 in 100 and subjected to the same amount of traffic, will require from 15 to 25 per cent. more material to maintain the surface in an equally good condition. The annual wear in thickness of a metal coating may vary from one-third of an inch on light trafficked roads to 3 or 4 inches on roads subjected to heavy and continuous traffic.

It is difficult to measure the annual wear, as the depth generally given is that of the material laid in a loose state and subsequently consolidated by wheel traffic.

359. The quantity of material necessary for repairs is usually stated at so many cubic yards or tons per mile of road. On roads over which the traffic is light the annual quantity of macadam necessary for repairs may not exceed 20 cubic yards per mile, while for ordinary country main roads the average consumption of material may be taken at 40 to 50 cubic yards per mile, and for roads situated between large towns the annual amount of metalling requisite to keep the surface in good repair may amount to 200 or 400 cubic yards per mile. In the vicinity of large manufacturing towns, however, the quantity may rise to 700 and even to 1000 cubic yards per mile per annum.

Very interesting comparisons could be made of the wear of roads under

different circumstances if accurate data could be obtained of the amount of material applied in repairs, and of the traffic passing over a given length in a given time.

To add still further to the difficulties which beset this subject, the nature of the subsoil and the condition of the drainage have to be taken into consideration, while the quality of the material employed for repairs is a factor which enters largely into the question.

360. To exemplify how much depends on the quality of the metalling made use of for repairs, and, consequently, the number of cubic yards applied on each mile of road during a season, the following may be mentioned :—

Previous to steam road-rolling being introduced, the different lengths of roads under the author's jurisdiction were maintained on the patching system from various quarries, the material from the nearest local source being generally employed.

One of the sections of road referred to, although in very good condition, was entailing a greater cost for maintenance per mile than other portions of the same road under similar conditions as to traffic, gradients, and exposure to the action of the sun's rays. The surface and subsoil drainage were examined, but as they were found to be in good order the cause of the difference had to be sought for elsewhere. The amount of scraping and cleaning was much greater in proportion to that on the adjoining portions of the road, while the annual consumption of metalling was relatively much higher. This clearly pointed to the quality of the macadam, which was to all appearance of a suitable nature, but did not give equal wearing results under traffic. The metal of which this particular section of the road was repaired cost 4s. per cubic yard deposited in depôts, the quarry being situated within an easy carting distance.

The quarries yielding the material for repairing the adjoining sections of the road were situated at a considerable distance, but under the circumstances it was considered desirable to rearrange the source of supply from which the metalling for the portion of road referred to should be obtained.

To supply stones from the other quarries involved an additional cost, principally for haulage, the average price being 5s. 6d. per cubic yard. The quantity of metalling applied each year previous to this was 150 cubic yards per mile, which meant at that quantity an additional annual outlay of £11, 5s. for road metal alone.

It was observed, however, that in the course of two years the condition of the surface of the road was such, and the manual labour had decreased so greatly, as to warrant the annual amount of metalling for repairs being reduced by 50 cubic yards per mile of road.

It is obvious that by the judicious application of a durable material, economy in the cost of maintenance is ultimately attained, while the condi-

tion of a road is improved, and the tractive effort of horses reduced. The actual cost of maintenance, including labour, in the case mentioned was, by substituting a better quality of macadam, reduced by £5 per mile, which at first sight does not appear a great saving, but, assuming the principle to be applicable to many miles of roads, under similar conditions to those in the one pointed out, the annual expenditure might, in many instances, be considerably reduced.

For this reason and many others, and with a view to efficient labour and attention to drainage, comparisons should be made of the annual expenditure on different sections of roads similarly situated, so that when excessive differences arise, the whole expenditure may be analysed in detail, and the causes of the apparent discrepancies ascertained.

361. Cost of Maintaining Roads.—The annual cost of maintenance per mile of roads, like the quantity of metalling applied, is a very variable figure, and depends on the amount of wheel traffic, the quantity and quality of the material employed for repairs, the distance of the source from which it is obtained, the situation of the roads being open, and with favourable gradients for efficient drainage or otherwise, and the cost of labour in the particular district.

A road repaired with suitable material on a well-drained subsoil, exposed to the action of the sun and air, and over which there is a moderate amount of traffic, may be maintained for a trifling sum for each mile per annum. On main roads, however, where the wheel traffic is much heavier, the annual cost for maintenance may vary from £20 to £70 per mile, while on suburban roads and those situated between large cities, the cost per mile may range from the latter figure to £200 or £300 per annum.

362. It is stated, on the authority of Mr. Browse, that in 1856 the cost of the yearly maintenance of the road over Westminster Bridge (which, since that time, has been paved with causeway setts, and is now laid with wood blocks) was at the rate of £3300 per mile, the average wear of the granite macadam being 5½ inches. Other figures give the annual cost of maintaining macadamized roads on some of the streets in London noted for their incessant and exceedingly heavy traffic, which have since been paved with setts or wood blocks, at 2s. 9d. to 3s. 6d. per square yard. It is, however, necessary to bear in mind that the cost of granite metalling (Guernsey) is 14s. to 18s. per ton delivered in London.

363. Relative Proportion of the Combined Cost of Maintenance.—The relative proportion of the outlay on manual labour and materials to the combined cost of maintenance will vary according to the requirements of a road and the price which is paid for the macadam, the distance hauled being an important factor in the case.

On light-trafficked roads the cost of manual labour will be increased in proportion as the amount of material applied becomes less. In the case of

these the cost of manual labour ranges from 40 to 50 per cent. of the combined expenditure, while the proportion, when the quantity of material employed each year is from 100 to 200 cubic yards per mile, procured at an average cost, may be only 25 to 30 per cent. of the combined cost.

In the case of some of the busy thoroughfares in London, where the quantity of metalling applied on the roads each year exceeded 500 cubic yards, and the annual expenditure was about £400 per mile, the proportion of labour probably did not exceed 18 per cent. of the combined cost.

It may be observed that on country roads the average cost of maintenance varies considerably. Many roads or sections of a length of road are kept in good order for £7 per mile per annum, while on roads over which a heavy wheel traffic passes, the yearly expenditure for maintenance on short lengths may cost £100, £200, or even £300 per mile.

364. Methods of Repairing Roads.—The repairing of the surface of roads may be carried out either by placing new materials in thin coats and small patches year by year, known as the 'patching' system, or by spreading a coat of metalling of varying thickness, according to requirements, and consolidating the material by steam rolling.

In the former case the loss by wear caused by the wheel traffic and weather is replaced annually. In practice it is found that the wear and the thickness of the material composing the crust of a road are very irregular, consequently it often happens that under certain circumstances portions of a road are coated more frequently than others which are more favourably situated.

The new materials should be spread on the parts of a road which requires them, namely, in hollows or depressed and weak places, with a view to making the most frequently traversed portion of the road as far as practicable of uniform strength. The number of years which will elapse before the whole wearing surface of a road will be covered, assuming it to be of a nearly uniform strength throughout, will depend chiefly on the amount of vehicular traffic passing over it, and the quality of the metalling employed. The number of cubic yards, therefore, which it is necessary to spread over the surface in patches on a stretch of one mile of road each year in order to keep it in proper condition, will depend on the requirements of each particular case.

365. A cubic yard of ordinary unscreened hand-broken macadam, from ½ inch to 2¼ inches in size, will, if carefully spread, cover about 28 to 30 square yards of road surface one stone thick. If the material is screened to a size similar to that passing from a breaking machine, the area which one cubic yard will cover, the stones just touching each other, only amounts to 24 or 26 square yards. In the event of the macadam being packed close, as is usually the case when it is spread in connection with rolling operations, the

area covered will not exceed 16 square yards, while 1 ton of 2½-inch screened macadam covers about 13 square yards.

From these figures can be ascertained the number of square yards of surface which can be covered when the quantity of material which is allocated to each mile of road is known. Thus on a road 15 feet wide, with an annual supply equal to 175 cubic yards of macadam per mile, each part of the road would be coated once every two years. Taking the quantity of metalling at 40 cubic yards per mile per annum with the same width of road, it would take a period of nearly nine years before the whole surface could be coated. On a roadway 30 feet wide, the whole surface would be covered every two years with a quantity of 350 cubic yards per year per mile, or every four years with an annual supply of 175 cubic yards per mile.

It is evident that certain parts of a road must undergo wear for many years without needing to be coated, while it is obvious that certain parts of the roads repaired by patching must necessarily be less strong than other portions. The road may be able to withstand the ordinary traffic, but in the event of excessive or exceptionally heavy traffic coming upon it, combined with bad weather, the crust of the road, especially where the next annual coating of metal will in all probability be spread, would suffer owing to its weak state of repair. Heavy weights traversing a road, irrespective of its strength to bear them, will cause considerable damage, and in all probability reconstruction may be necessary at places.

In applying small coatings of metal, it is usual to spread a patch alternately on either side of the crown of the road, and, when necessary, on the centre, leaving a sufficiently clear space between the coatings so as to 'force' the vehicular traffic to follow a winding track, while the horses' feet can avoid coming in contact with the stones. This means of consolidating the freshly laid metalling is naturally avoided where possible by those using the roads, so that the remainder of the road surface will receive an undue share of the traffic, with the result that considerable wear is caused in places least able to bear it. By exercising care in the spreading of the metalling, which is to be worked in by the wheels of vehicles, and attention to the patches during the process of consolidation, great annoyance and inconvenience to those using the roads may be avoided; while the damage to horses and vehicles, resulting from this cause, may be reduced considerably.

The patches of macadam which are to be consolidated by wheel traffic should not exceed 4 to 5 yards in length, and from 1½ to 2 yards in width. In order to ensure the gradual working in of the metalling by the wheels of vehicles, it is desirable to spread a quantity of the small material round the edges of the metal patch. This will enable the wheels of vehicles to work gradually from the sides to the centre of the patch.

The practice of stocking the surface or loosening the old material with picks where the new macadam is to be applied is seldom resorted to.

Generally the weather prevailing during the winter months in this country presents but little difficulty to the process of incorporating the new metalling with the old surface by the ordinary wheel traffic, although the time occupied in consolidating the macadam may vary from two to five months.

366. Time of Year when Repairs should be carried out.—The precise time at which to commence applying the road metal will depend upon the climate, weather, the nature and strength of the road, and the class of material employed. The autumn and early winter, provided the surface is in a slightly soft condition, is generally the season for applying the bulk of the macadam. On many roads fully 75 per cent. of the material is spread at the first operation, while on some roads, especially those over which there is a heavy traffic, only about 50 per cent. of the total quantity is applied in the first instance. In the latter case, and after the first coat of metalling is well set, a further quantity, amounting to about 25 per cent., is applied generally in the month of January, the remaining 25 per cent. of the total quantity of macadam, which is usually of a small size, being spread in either case about the middle of February or beginning of March; this is known as 'spring patching.'

Should the rainfall during this time of the year be under the average, or otherwise dry, the vexed question of using a binding material will present itself.

Under normal conditions of rainfall, the amount of material for repairs necessary to be applied so as to keep a road in good condition will, apart from the amount of wheel traffic, be greatly affected by the weather. When the quantity of macadam used per mile of road per annum is determined in relation to the position the road occupies, the amount of wheel traffic which in ordinary circumstances traverses it, and the average rainfall, there should be little difficulty, by judicious management, in having all the coatings thoroughly set by the beginning of April each year. During a dry season, however, although the surface of the road was in suitable order when the metalling was applied, a binding of some kind is necessary to retain the stones in position, if not also to aid the consolidation of the coatings. Binding, or rather 'blinding,' should not be spread over macadam lying in a loose open state, otherwise the surface will become rough, and the ultimate wearing capacity of the coating be greatly reduced. Generally speaking, binding should not be applied to the metalling unless the coatings are partially set or consolidated, and then only during the spring months, in order to give a smooth surface, and preserve the macadam from being crushed; but it may be absolutely necessary to apply it owing to the absence of moisture to effect this properly.

367. The practice of using blocks or trestles to force the wheels of vehicles on to the metal patches is a primitive method of aiding in effecting consolidation, but one which, under adverse circumstances, is inseparable

from the mode of repairing roads by means of spreading isolated patches of macadam on them. The use of these should be restricted as much as possible, and resorted to only when damage is likely to occur by reason of the vehicular traffic running in one track after the supply of metalling is exhausted.

368. Composition of the Crust of a Road.—The composition of the crust of a road that has been repaired by a system of patching is made up of a high proportion of detritus in combination with the metalling forming the wearing surface.

Experiments have been made to ascertain the composition of traffic-consolidated road surfaces or the proportion of solid material to that of voids or spaces filled with small stuff or muddy cementing material.

Observations on metalling broken by hand to pass through a 2¼-inch ring show the average proportion of solid to void to be 56 per cent. and 44 per cent. respectively.

During the process of consolidation by the wheels of vehicles, a considerable amount of the material is reduced to dust and small chippings. This waste, brought about by abrasion, is estimated by some authorities at 30 per cent.; to a certain extent it assists in filling the voids of the macadam, and in the consolidation of the coating. The greater portion of this waste is, however, scraped off the road in the form of mud.

If a portion of a well-kept wheel traffic made road, repaired with hard whinstone or basalt, be taken up, and the component parts of the sample separated so as to exclude all material which will pass through a half-inch riddle, a size that may be fairly considered as exhausted macadam, it will be found to contain on an average 56 per cent. of solid and 44 per cent. of void detritus.

This proportion, it may be observed, is similar to that of the original metalling.

369. Mr. Codrington, when acting as Superintendent of the County Roads in South Wales, carried out many experiments in connection with the composition of road coatings on roads repaired with different kinds of material.* The average results he obtained show that 39 per cent. of the material composing the constituent parts of the crust was made up of stones over ⅞ths of an inch in size, 44 per cent. of small stuff from less than ⅞ths to $\frac{1}{30}$th of an inch, while 17 per cent. consisted of detritus or mud. This is practically equal to 39 per cent. of solid or serviceable material and 61 per cent. of void or small exhausted macadam and mud, although in some cases the proportion of solid to void was nearly equal. The material was originally 2¼- and 2½-inch metalling, but was principally composed of mountain limestone.

He also states that specimens of consolidated limestone roads weigh from

* *The Maintenance of Macadamized Roads*, by Thomas Codrington, second edition, 1892, pp. 54 and 55.

161 to 163½ lbs. per cubic foot, when the limestone of which they are repaired weighs 171½ to 172 lbs. per cubic foot, the consolidated road being thus 93½ to 95½ per cent. of an equal bulk of solid stone. The same proportion was found to prevail on consolidated road surfaces composed of metalling prepared from igneous rocks.

370. When the metal coatings of roads contain a large proportion of mud and small-sized stones, such roads will not be capable of withstanding the wear occasioned by the passage of heavy traffic during wet weather, or when the crust of the road is in a soft state. Alternations of frost and thaw in such roads will likewise destroy the coating and reduce the better portions of the metalling quickly to detritus, more readily than in a road the constituent parts of which are mainly composed of serviceable material. Under the latter conditions, and with efficient surface and subsoil drainage, these atmospheric influences have but little damaging effect.

The inconvenience experienced, and the great waste of material inseparable from the old method of repairing roads by patching, however well carried out, cannot be compared with an efficient system of steam rolling, and this mode of repairing roads will now be described in detail.

371. **Steam Rolling as applied to Repairing Roads.**—In many countries the methods practised in obtaining the material, the subsequent means adopted in reducing the rock to macadam, and steam rolling, are carried out on thoroughly scientific principles. Apart from the great advantages to those using the roads, and which are of primary importance to owners of horses, a considerable economy in the maintenance of the roads, compared with the old system of performing the work, can be shown to result from the employment of an efficiently equipped road maintenance plant.

The construction of the steam roller has been already described, and no matter what the weight of the engine employed to perform the work of consolidating the metalling may be, the method is precisely the same, although the cost of rolling will be somewhat higher when rollers of the light class are made use of.

A system of rolling practised in some of the counties in this country is that of consolidating the metal patches which were formerly allowed to be worked in by the ordinary wheel traffic.

The area to be covered is generally loosened by means of hand picks, or by a scarifier, previous to the new metalling being applied. In most cases, however, the edges of the worn-out parts to be renewed are only loosened, so that the macadam forming the outside of the patches will not be crushed by the roller wheels during the process of consolidation.

If the surface of a road contains a considerable amount of detritus or is previously softened by artificial watering, the macadam, which can only be spread one stone thick in this method of repairing, may be consolidated without much damage being done to the metalling. Under ordinary circum-

stances, however, the portions of the road to be repaired should be picked or scarified, otherwise the macadam will be, to a great extent, pulverized by being placed between two hard substances, namely, the surface of the road and the roller wheels. In rolling patches of metalling it is necessary to sprinkle water over the surface to aid consolidation, the detritus in the old macadam being generally sufficient to form a binding for the new coating. This is swept over the surface; then, by repeated passages of the roller with occasional watering, all the interstices of the stones are filled up and the surface is made perfectly hard and smooth.

This method of improving the surface of roads is undoubtedly a very decided advance on the barbarous system of consolidating the macadam by the wheel traffic formerly resorted to, and which, unfortunately, is still in operation in many districts at the present time. It must be admitted as a general principle, however, that when rolling patches of metalling, the whole width of the roller wheels cannot be brought into use simultaneously or continuously. For very small repairs, or on roads which have been rolled and are slightly out of repair at places, the process of mechanical scarifying, applying a small quantity of fresh materials, and rolling, improves a road surface considerably, and it may thus be made nearly equal in durability and appearance to a road which has been coated and consolidated.

372. Rolling Patchwork.—The following is an instance, and the remarks are applicable to a greater or less extent in rolling all metal patches.

When a patch of metalling, 3, 4, or 5 feet in width, has to be consolidated, the effect of rolling is such that a part of the breadth of the engine wheels overlaps the metal patch, consequently that part is doing no actual work so far as consolidating the new coating of metal is concerned. It has been already stated that the rolling width of a 15-ton roller is $7\frac{1}{4}$ feet, while in one of 12 tons weight it is $6\frac{1}{2}$ feet; hence, to obtain the advantage of the full effective width of a roller the breadth of the metal patch would require to be increased accordingly. This, in effect, means adapting the extent of repairs to the rolling width of the engine, irrespective of the actual necessities of the road. Assuming, then, that this has been satisfactorily arranged, the length of the metal coating has to be considered, and it may happen that by this system of working the new material is spread with but little space between the patches, which will admit of the maximum amount of surface area of metalling being rolled. It is obvious, nevertheless, that as the roller commences work clear of the metal patch, or on the old portion of the road (a process which is repeated each turn the engine makes), and also overlaps the width, a considerable amount of the benefit of rolling is wasted on the portion of a road which is probably in excellent order. In other words, the cost of rolling patches of metalling is considerably greater than when continuous coatings are spread to the full width.

The author has found from experience that 30 cubic yards of metalling

spread in isolated patches can be consolidated during the autumn and winter months with a 15-ton roller.

373. Cost of Rolling Patches of Metalling.—The cost of rolling thin coatings of metalling applied on the patching system, including sweeping, horse, and water tank, but exclusive of spreading the macadam, is 8d. per cubic yard. It is necessary to add, however, that in some cases many of the patches were partially consolidated by the wheel traffic previous to the work being undertaken by the roller.

The County Surveyor of Nottingham * has carried out the patching system of repairing road and steam rolling on an extensive scale for some years past with good results.

He uses 12-ton rollers, and the average cost of consolidating the metalling, including small repairs to the plant, is 9d. per ton. This is an average for working all the year round, the operations being carried on during the summer months on the roads which are nearest the best supply of water.

This system is mostly followed where limited quantities of metalling are applied annually, and especially when the cost of the broken stones reaches a high figure, the object being to obtain a smooth surface, but so treated a road would, of course, not have a reserve of strength capable of withstanding fluctuations of traffic.

The quantity of material spread in patches which can be consolidated by the roller each day under ordinary circumstances is on an average 30 tons; in many instances, however, 20 tons may be considered good work, especially where the exigencies of the passing traffic necessitate frequent stoppages during the operations.

374. Rolling Continuous Coatings of Metalling.—For the reasons given, and because of the time lost by the roller travelling to distant parts of a district repeatedly year after year, the author prefers to consolidate coatings of metal in long stretches spread to the necessary width, as the experience gained in carrying out the two systems clearly shows that in that here referred to there is greater economy in working expenses as well as increased efficiency.

The roads are also more uniform in strength, while a more regular wearing and durable surface is obtained by a system of continuous coatings with consolidation by steam rolling.

The additional quantity of metalling necessary to keep a roller constantly at work in some districts might, at first sight, be considered a serious obstacle to the introduction of road-rollers on economical grounds alone. No doubt this would be the case if, in addition to the annual quantity usually allocated for patching purposes, a great amount of metalling were supplied to coat long stretches, or otherwise to ensure the roller being continually employed.

375. By adopting a graduated system, however, so that certain roads,

* A Paper read before the Incorporated Association of Municipal and County Engineers, vol. xxii., on 'Steam Rolling,' by E. Purnell Hooley.

to be rolled in the course of a period of three or four years, may be arranged for in advance and added to as the work proceeds year by year, the previous annual quantities of material applied to these roads can, by judicious management, be reduced considerably in view of a thorough repair being undertaken within a limited period of time.

In working out this system of concentrating the metalling, due consideration must be given to the requirements of particular roads and certain sections of a road, where circumstances indicate that attention and the application of macadam are necessary to prevent the crust of the road becoming destroyed. It is advisable, not only when rollers are being introduced for the first time, but as rolling operations are extended, to prepare a list of those roads which it may be considered necessary to undertake in the first instance, and those to be dealt with later in rotation.

376. The roads, extending probably many miles, which it is intended to roll during the season following the previous year's supply of metalling, should be repaired by only employing the quantity of material that is just sufficient to maintain a fairly good surface without allowing the road coating to become tracked.

By this means, and when the following year's supply is prepared, a quantity of macadam nearly equal to two years' ordinary allocation is thus reserved until the rolling operations are commenced. This arrangement may be extended so that a three or four years' supply may be applied and rolled on any particular road.

As a means to an end, this is the only method which can be followed, unless larger quantities of material can be procured at a cheaper rate. Methods have been described in the chapters on Quarrying and Stone-breaking, by which material can be procured at a small cost.

Undoubtedly a country road can, by careful attention, be kept in good repair with a small quantity of material for a limited period of time, and by allocating a quantity of macadam, to be applied only when the road shows signs of giving way, a large amount of metalling may be reserved and concentrated on roads where found necessary in connection with rolling operations. Adverse weather in the form of alternating frost and thaw, will no doubt injuriously affect certain portions of the road surface, but apart from a trifling expenditure in labour to remedy this, the weak spots can be specially treated previous to or at the same time as the general repairs are effected.

It has already been shown that under the old system of repairing roads by patching and consolidating the coatings by wheel traffic, a layer of macadam one stone thick serves to bear the ordinary traffic without failure of the road surface for a considerable number of years. Any reduction, therefore, of the annual quantity of metalling applied, as a temporary measure, will not materially affect the strength of the road for a time.

Experience shows that by judiciously arranging the annual allocation of material for repairs, the actual quantity previously used can be reduced by 75 per cent., when rolling operations are to be undertaken the following season, and 50 per cent. in the case of roads which are to be rolled the second year. On these roads which are to have attention during the third season, a quantity of metalling amounting to a 25 per cent. reduction on the former quantity applied will be sufficient for ordinary repairs. It is obvious that by this method of reducing the quantity of road metal, in advance and in regular rotation, a sufficient supply of material will be provided to keep the roller employed in consolidating either large patches of metalling, or wide continuous coatings. It may be well to state here that a reduction in the quantity of metalling used, when spread in continuous stretches and rolled, will give a saving of about 25 per cent. of the total amount formerly applied in patching which was consolidated by vehicular traffic.

377. If the macadam used for repairs is hand-broken, it can be stored in depôts or brought direct from the source of production to the road under repair, care being exercised to avoid unnecessary haulage, which, besides entailing extra cost, does not add in any way to the efficiency of the work.

It happens at times in some counties that a supply of suitable material cannot be obtained in the immediate neighbourhood of the roads to be repaired. This may necessitate the metalling being brought from a considerable distance, even from points beyond the limits of the county where the operations are to be carried out. In such circumstances the cost of maintaining the roads is considerably increased, owing to the high rate paid for haulage by rail or otherwise, which often amounts to three or four times the initial cost of the macadam at the source of production.

378. Example of the Methods adopted in Arranging for Rolling Operations.—Where quarries exist, the rock of which is suitable for producing road metal, and are so conveniently situated in relation to the road where the repairs are to be made that the material can be conveyed by carts or by engines and traction wagons, the following method of arranging the work is usually adopted.

The fixing of the portable stone-breaking machine and all the other accessories being arranged as described in Chapter VI., the points on the road at which the supply of metalling should commence and terminate from the different quarries may best be illustrated by giving an example taken from actual practice.

A road, A B, fig. 120, extending to 5 miles, was repaired by a continuous coating of metal, the width ranging from 14 to 18 feet, while the depth of the macadam varied from one stone thick to 4 inches. The section A *d*, of the main road A B, had been previously maintained with material of a hard and tough nature, over which a heavy traffic passed. The surface

of the road was considerably worn, which necessitated a coat of metalling 4 inches thick being applied.

The section *d e* was repaired with the same material as the previous section, but the traffic passing over it was of a moderate description; the repairs being effected by scarifying the old surface, bringing it into proper contour, and applying a coat of metalling one stone thick. The section *e* B, the wheel traffic over which is considerable, was maintained with a material of a highly siliceous nature, while the surface had become badly cupped, necessitating the coating being scarified and the old material screened to remove the high percentage of small or exhausted material.

This small stuff was laid aside and used afterwards for binding the new metal coating, the thickness to which the macadam was laid being 3 inches between *e f*, and 4 inches between *f* B.

The quarries from which the metalling was taken are marked *a*, *b*, *c* in fig. 120.

In deciding from which of the two quarries *a* and *b* the material should be taken for repairing the portion of the section from A towards *d*, the

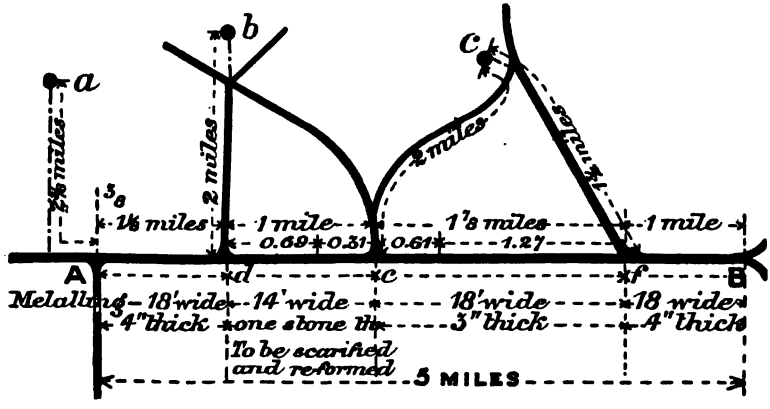


FIG. 120.—Plan showing how to economize haulage from quarries to main road.

rock being of equal quality, the relative distances and the probable expense of working had to be taken into consideration.

The conditions as regards the access to, and the service roads leading from both quarries were very much alike, consequently the cost of haulage per ton-mile did not enter into the question.

The point to be decided was the distance from the points *a* and *b* to the commencement of the section at A. On referring to the measurements on sketch plan, it will be seen that, so far as the mileage is concerned, the quarry *a* would, for a distance of ⅜ths of a mile from A towards *d*, be the preferable one so far from which to procure the material for repairs. The quantity of macadam required for this section A *d* of the road, to the width

and thickness of coating shown, would be 495 tons, which could be accomplished in about nine days by means of a stone-breaking machine.

Subsequent to breaking this quantity of macadam the stone-breaker would require to be removed to the quarry *b*, so as to equalize the cost of haulage; but the removal of the plant from the quarry *a* to that at *b*, including dismantling and re-erection, would entail an expenditure of 50s. The cost of production therefore would, considering the short period which the plant was required at quarry *a*, be enhanced by about 1¼d. per ton, compared with the cost had the breaking machine been set to work in quarry *b* in the first instance.

The expense of one change or removal was thus avoided, and although the haulage cost more, the total expenditure incurred in repairing the section A *d* was less by procuring and breaking all the metalling required from one quarry, instead of, as contemplated at first, dividing the quantity between the two quarries *a* and *b*. The cost of removing the plant from one quarry to another is infinitesimal when calculated at so much per ton on a large quantity of material, while it is considerable when only a few days' breaking is undertaken, by reason of the high proportion of the time required for removing the machinery, to the actual amount of work performed. In other words, the additional cost for breaking by machinery amounts to 1¾d. per ton when the plant is removed each week, while it is under ½d. per ton of macadam broken, if a month's work be accomplished before commencing operations in another quarry, compared with a longer period of time.

It will be obvious from these considerations, that the most economical arrangement was to procure the whole material necessary for repairing the section of road mentioned exclusively from the quarry *b*.

The points *d* and *e* on the road, being situated exactly at the same distance from the quarries *b* and *c*, would, if the conditions were equal, present no difficulty in fixing on the point as that midway along this section, where the cost of haulage from either quarry is equal.

The road from the quarry *c* is of an undulating nature, however, which involved an increase for haulage of 1¼d. per ton-mile compared with the cost of haulage from the quarry *b*. The question presents itself in this way: at what point between *d* and *e* does the cost of haulage from either quarry become equal? This is simply a matter of calculation. With regard to the section *e f*, similar conditions as to haulage existed, and the road from the quarry *c* to B being on a gradual descent, the price per ton-mile for haulage was similar to that from the quarry *b*, namely 7¾d. As in the preceding case, it is necessary to calculate the cost of conveying the metalling, so that where the materials applied to the road from the two quarries meet, the expenditure for haulage in either case will be the same.

The spreading of the macadam, and therefore the rolling, should be commenced at the part of the road to be repaired which is farthest from the

source of supply; that is, when breaking in quarry *b*, the repairing of the road should be commenced at the point A, and be continued towards *d*. The portion of the section *d e* should likewise be arranged for by fixing the point where the operations are to be commenced, and working back to *d*.

379. Haulage—how arranged.—By arranging the work in this manner the carts or wagons employed in conveying the metalling do not pass the roller, and therefore do not interrupt the work of consolidating the metalling.

In conveying the road metal by team labour direct from the stone-breaking machine, or even when taking it from depôts, tip-carts only should be employed in depositing the macadam on the road, as by so doing the men spreading the material can regulate the supply when being emptied, and so save extra labour in handling.

The macadam is thus placed approximately in position, but all the material should be turned over by shovels so as to equalize the coating. With well-screened metalling less time is necessary to accomplish this than in the case of spreading hand-broken stones or material containing a large proportion of small or of irregular-sized stuff; it is necessary in either case, however, to employ thoroughly experienced men to perform this work, as the future durability of the coating, although rolled, will greatly depend on its having been properly done.

380. The spreading of the metalling, as already stated, is commenced at the point furthest from the quarry, and when a stretch of about 30 lineal yards of road has been coated the rolling is commenced.

To ensure that the proper quantity of macadam is being applied to the road, the area spread each day should be measured. On referring to the weigh-book, the total quantity of material removed from the breaking machine and deposited on the road is ascertained, when it can be easily verified if the proper depth of metalling is being adhered to.

381. Binding Material and Artificial Watering necessary.—Previous to, and during rolling operations, binding material should be prepared from the road sides, if suitable, or brought from the nearest available source, and deposited conveniently on the bermes or in the water-tables on either side, and all the water outlets should be closed.

The rolling, as explained in Chapter VII., is commenced at either side nearest the water channels; the engine is worked gradually towards the crown of the road, and repeated passages are made in order to set or interlock the macadam, during which process the flat sides of the stones are brought uppermost. After this has been accomplished, and then only, the artificial watering is commenced, when, according to the nature of the material and weather prevailing, the binding is applied; the new metalling being wet prevents its being 'licked up' by the roller wheels.

When clean sand is the material made use of for this purpose, it should be spread over the partially rolled metalling evenly and in small quantities as

the roller passes backwards and forwards, the interstices being gradually filled by watering and sweeping, until the whole surface is thoroughly consolidated and presents a mosaic-like appearance. If sand is applied before the metal coating is well set, it will be washed to the bottom of the macadam and cause trouble afterwards. When the binding material is composed of loamy sand, road-drift, or road sweepings, from which the vegetable matter has been removed by being properly weathered, the system of working adopted on roads up to 18 or 20 feet in width is to convert the binding in the water-tables into a grout by a copious supply of water, and passing the roller wheels over it. The binding, in this consistence, is then swept from either water-table towards the crown of the road, when by the repeated passing of the roller the whole body of the macadam is bound together. The process of rolling with a slight watering should be continued even after the surface appears to be consolidated, as by this means any surplus binding lying in the interstices of the stones will be squeezed out, and should be swept to the sides.

382. Amount of Rolling necessary.—The amount of rolling necessary will greatly depend on the nature of the material and binding used, therefore no specific rule can be laid down; experience and observation are the only guides.

Generally speaking, a sufficient degree of consolidation will be attained when the stones cease to creep or move under the action of the roller wheels.

A method of testing sometimes adopted is placing a single piece of road metal on the surface of the newly consolidated coating; should the stone be crushed to pieces instead of being forced into the general body of the road, a sufficient degree of hardness is considered to have been attained. This may be applicable in some cases, but as the quality of the metalling depends on this method of determining the degree of consolidation, it is not a very reliable test.

As all binding material contracts after the moisture evaporates, the metalling at the surface, especially during dry weather, becomes slightly loose. It is necessary, therefore, to apply some light binding material to counteract this tendency, for which purpose a thin coat of sand $\frac{1}{4}$ inch thick spread over the surface is particularly useful, but during high winds it is easily blown away, leaving the surface of the road bare and unprotected.

The best material which can in any circumstance be applied is, in the author's experience, the fine chips or screenings from the stone-breaker, which, being of some weight, are not so liable to be thus disposed of.

These binding materials should be applied immediately after the rolling proper is finished. It is advisable and, in most instances, necessary, on the advent of rain to send the roller over the newly finished road again. By doing so, every advantage is brought to bear on the metal coating, as the

lower part of it, being in a partially moist or green state, and the surface covered with a thin layer of chips, the whole mass is thoroughly compacted and a smooth hard surface formed.

This produces a 'skin' capable of resisting, under most circumstances, the destroying influence of dry weather and traffic on a newly rolled road, especially when the binding material used is of the kind mentioned. In the absence of rain it may become necessary to apply artificial watering to ensure a properly finished surface.

These remarks apply where in the rolling operations there is used only as limited a quantity of binding as possible, consistent with the proper cohesion of the macadam, and not to the system of using unsuitable material for this purpose, applied in immoderate quantities, which will give so much trouble in the subsequent maintenance of a road.

383. Hand-broken road metal applied without being screened, especially when the proportion of small material in its bulk is large and rolled in the usual way, presents a cupped surface in a few months after the work is completed. This is brought about by the material not being of a uniform size; the spreading of it equally over the surface of the road is a very difficult matter indeed; and should the metalling be prepared from rock of a highly siliceous nature, the process is well-nigh impossible.

384. The traffic carried on narrow wheels will in a short time wear out the parts where the small material has been spread and cause hollows to be formed, owing to its not being equal in strength to the proper sized macadam composing a portion of the coating.

A greater quantity of ordinary hand-broken metalling can be consolidated by a roller in a day than when machine or screened hand-broken is employed. In other words, the cost of consolidating ordinary hand-broken macadam is less per ton than when screened material is used.

385. **Method of Applying Scarifying Machine.**—A machine for scarifying the surface of a road is a very valuable adjunct to road-rolling, and may be applied in various ways. Many old roads containing a sufficient amount of metalling, and over which the traffic is of a light description, can be scarified 3 or 4 inches deep, brought to a uniform contour, and rolled, so as to present a smooth and hard surface. This may be carried out at a trifling cost, and will effect the improvement of making a good serviceable road of one previously in an unsatisfactory condition. The operation, whether for improving an old road or for the purpose of applying a light or heavy coat of metalling, is carried out in a similar manner.

The first cut when using Morrison's scarifying machine is commenced at the side and continued towards the crown of the road; then the engine is reversed, and the work done on the other side. The scarifying is best performed in the early morning, when, as a rule, the passing vehicles are not so numerous. Two hours each day is, in ordinary circumstances, ample time

for this work in scarifying an area sufficient to admit of the daily supply of material from the stone-breaker being spread over the loosened surface.

It is sometimes advantageous, however, when the consolidation of the new metalling is well advanced, to keep the machine at work for three or four hours, which will be sufficient for two days' rolling. It is not advisable to exceed this amount, except on roads where the traffic is very light, as the passage of the wheels of vehicles partially consolidates the newly scarified surface, especially during wet weather, which involves extra labour; the work must then be supplemented by hand picking.

After the whole surface is scarified, men are employed to rake the material into proper shape, so as to present a uniform contour, any large stones turned up being broken to a proper size previous to the application of the new coat of metalling.

386. Scarifying and Screening the Old Metalling.—The crust of a road which has worn down in a uniform manner is best repaired by applying a coat of metalling without the old surface being scarified. It is usual, however, to run a cut with the machine on either side of the road where the width of the coating is to terminate.

When such conditions exist, it may be considered to be an ideal wearing road. This is only attainable when a tough weather-resisting material has been employed, when the subsoil and surface drainage is perfect, and when the road is open and well exposed to the beneficial influences of sun and air. In most cases it is preferable to scarify the whole surface of the road to be repaired, and when the old metalling is such that the proportion of small material to the full-sized stones is not great, all that requires to be done to prepare it for the fresh macadam is to rake the stones composing the old material into proper contour. This is the simplest method of combining a system of scarifying and rolling, and is the invariable practice where these modern appliances are in use. At first sight this appears to be all that is required, but if a portion of road newly scarified, other than that already mentioned in the preceding paragraph, be examined, it will be found to contain a large quantity of stones varying in size from a $\frac{1}{2}$-inch gauge to the size of a pea, and a considerable amount of fine detritus. On most roads maintained by the aid of wheel traffic consolidation, the quantity of such material, which may be considered the exhausted portion of the crust of a road, amounts to, on an average, from 60 to 70 per cent. of the whole mass.

The quantity, of course, varies greatly, according to the condition of the road surface and the quality of the macadam which has been employed in carrying out the repairs; and in isolated cases the quantity of exhausted to serviceable material has been found to reach as high as 90 per cent.

In the case of roads repaired with a thick coating of metal and steam-rolled, the original proportion of binding to metalling was on examination found to be 15 per cent., and when scarified years afterwards to admit of

further necessary repairs, it was found to contain about 40 per cent. of exhausted material. This small stuff, or exhausted material, was determined by what would pass through a $\frac{3}{4}$-inch riddle or screen.

The reduction in the size of the metalling is caused by the wheel traffic passing over the road wearing the stones, especially during wet weather, and by the disintegrating influence of alternating frost and thaw. It may be observed that, even at a depth of 4 inches, a considerable amount of sand or detritus exists. Undoubtedly a large proportion of this is what may be termed 'soft or useless' material incorporated in the crust of the road, which, if allowed to remain when a coat of fresh materials is applied, will, after being rolled, give trouble sooner or later, and the result will be the formation of a series of hollows or cups on the surface of the road.

It is obvious that the direct cause of this unequal wearing is the large proportion of small to the ordinary class of material, consequently the irregular sized stones forming the old coating are of unequal strength.

387. On narrow roads the tendency of the traffic is to keep in one track, causing undue wear, while the other portions of the surface remain in good condition. When once these depressions are formed (the surface water being unable to reach the side channels), the road at these points is subjected to great wear.

To scarify the whole surface under these circumstances is unnecessary. What repairs are required may be accomplished by making one or more cuts with the scarifying machine along the depressed or cupped portions of the surface, applying fresh metalling one stone thick and consolidating by rolling, and a perfectly smooth surface will be the result.

388. When the system of repairing roads is carried out by patching and rolling, the work of consolidation is greatly increased by previously scarifying the surface of the road. By this method of executing repairs, the material can only be spread one stone thick so as to correspond approximately with the other portions of the road. If the surface of the road is not scarified, considerable damage to the metalling would result by the crushing effect of the roller wheels passing over the metal patches.

It is sometimes the practice to stock the parts of a road to be repaired by means of hand picking, but more frequently the outside edges only are loosened. This process is slow, and when only partially carried out results in damage to the fresh metalling, besides it is more costly than mechanical scarifying.

389. Thickness of Metal Coatings when Consolidated by Rolling.—A matter which deserves careful consideration is the quantity of material which should be applied for consolidation by steam rolling, in order to obtain the best results so far as durability and economy of maintenance are concerned. The amount in cubic yards of metal applied per mile of road, under the old or patching system, is so far a means of determining this

quantity approximately. To spread a coat of metalling the full width of a road and to a given thickness, it is evident that so many times the previous annual supply should be applied in order to give good results. The author has found in practice, that to obtain from five to ten years' service from steam-rolled coatings, due consideration being given to the quality of the material used and the situation of the road, an amount equal to four times the average annual supply formerly applied is sufficient.

Should the crust of a road be considerably worn, or when repairing light-trafficked roads, it is advisable to apply a proportionately larger quantity of metalling, but in no case need it be more than six times the annual supply allocated under the patching system.

In other words, a road which has been previously maintained in good order by an annual supply of 200 cubic yards per mile of road, would require, in order to provide a continuous coating for its full width, 800 cubic yards, or 890 tons, of metalling per mile. As in ordinary maintenance by patching, it is necessary, when carrying out the work by applying continuous coatings, to increase the thickness on the level stretches as compared with the other portions of the road situated on a gradient.

390. Method of Arriving at the Probable Cost of Repairing Roads.—In estimating the annual expenditure for steam road-rolling operations, it is desirable to make out a proper statement which should necessarily include the different items involved, from the time the material is quarried till it is consolidated on the road. By this means the actual cost of repairing any section of road can be ascertained, and valuable information is afforded for future reference and comparison. In the following particulars it is the intention to give all the details necessary for framing an estimate for such work, on any length of road or section thereof.

To illustrate this, let the length of road A B, fig. 120, taken from actual practice, be the section requiring repairs; the position of the quarries is represented at *b* and *c*.

As already pointed out, the cost of quarrying the material may vary within certain limits, partly owing to the nature of the rock, but mainly to the thickness of the stripping or tirring. Under ordinary circumstances, the inclusive cost of this may be put down at 7½d. per ton of rock sledged, ready to be wheeled to the breaking machine. The items for breaking and rolling must of necessity vary according to the size of metalling required, the capacity of the roller employed, and the available supply of water for carrying on the work of consolidation.

For the road under consideration the breaking of the macadam, including wheeling the rough material to the machine, and all other incidental expenses, may be taken at 1s. per ton, while the consolidation of the metalling, including 2d. per ton for spreading the coating, may be safely put down at 8½d. per ton. The following is a summary of these items.

TABLE XXXVII.

	Pence per ton.
Quarrying, including stripping and sledging, ...	7·5*
Breaking, ...	12·0*
Rolling, including spreading the macadam, team labour for water supply, sweepers, etc., ...	8·5
	28·0

or 2s. 4d. per ton consolidated.

The hauling of the material will, of course, vary according to the distance conveyed, and the nature of the service roads traversed.

The contract price for the section A *d*, in fig. 120, was 7¾d. per ton-mile, the thickness of the metalling applied being approximately uniform throughout the section; therefore the average cost on the length of road A *d* is taken as midway between these points. This average distance is made up as follows:

Distance from quarry *b* to point *d* =	2·0 miles.
„ „ *d* to A = 1⅛ miles ÷ 2 =	0·56 „
Average distance, ...	2·56 „

This at 7¾d. per ton-mile is 19·84d., which, added to the total of the other items, amounts to slightly under 4s. per ton.

The next matter to be considered is the quantity of metalling required to coat a road 18 feet wide to the average thickness of 4 inches. A cubic yard of macadam spread to an assumed thickness of 1 inch will cover 36 square yards of surface, and as a ton of metalling is one-ninth less bulky, one ton of road metal of a similar thickness will cover 32 square yards.

From this latter figure it is an easy matter to determine how many square yards of surface one ton of metalling should cover when the depth of the coating is stated.

In the present case it is 4 inches; consequently one ton will cover an area of 8 square yards. The area forming the section of road A *d*, is ascertained in the usual manner, and will be found to contain 11,832 square yards, which, divided by 8, gives the quantity of metalling required, namely, 1479 tons. The cost of carrying out the work is calculated by taking the latter figure at the price per ton for the inclusive operations, or 4s.; hence £295, 16s. is the cost for repairing this section of road extending to 1⅛ miles.

The second section of road to be repaired from the quarry *b*, extends to a point between *d* and *e*. This must be determined previous to commencing operations, for, should the distance be taken as midway between these

* These figures are purposely made high so as to cover all contingencies which may arise, the actual cost being generally about 8 per cent. less, as pointed out in the chapters on "Quarrying and Breaking."

points, the cost of haulage would, in the case of materials carted from the quarry *b*, amount to 19·38d. per ton, while that conveyed from the quarry *c*, would be 22·5d. per ton. To equalize the price for haulage from these two quarries, it is necessary to fix the point on this section of road where the cost of carting will be the same from either. This may be found by calculation.

The half-distance between the two quarries along the road is 2½ miles, but as the cost of haulage from the quarry *c* to this point is 1¼d. more per ton-mile than from the quarry *b*, it is evident that the point where the material from either quarry should join will be nearer *e*. The price for haulage is approximately 20·94d., being the mean between the prices from the two quarries at the half-distance. This figure divided by the prices per ton-mile from the quarries *b* and *c* respectively, will give the assumed point, thus: (1) 20·94 ÷ 9d. equals 2·327 miles, and (2) 20·94 ÷ 7¾d. equals 2·702 miles. On examination, however, it is found that the total distance is too great by 0·029 of a mile; to obtain the actual distance to the dividing line it is only necessary to deduct the half of the fractional part (·0145) from each assumed distance in order to arrive at the final result. Thus: 2·702 – 0·0145 equals 2·6875 miles, and 2·327 – 0·0145 equals 2·3125. The distance from quarry *b* is therefore 2·69, and from *c* 2·31 miles. The distance along the section of road *d e* is determined by these figures, being 1214 yards from *d* towards *e*, and 546 yards from *e* in the direction of *d*.

Had the half-distance along the road between the points *d* and *e* been adopted as the dividing line, overlapping would have resulted, and the cost of the work would therefore have been unnecessarily increased, by reason of the extra haulage. Taking the cost of quarrying, breaking, and rolling as before—namely, 2s. 4d. per ton—an additional sum will have to be added, as this section of the road is to be scarified and re-formed.

The cost of scarifying 3 inches deep may be taken at $\frac{1}{10}$th of a penny; to this has to be added a sum sufficient to cover the expense of raking the material into proper contour and breaking any large stones which may be in the old coating. This is generally equal to about ⅛d. per square yard, consequently these items together amount to 0·22d. per square yard.

The haulage from the quarry *b* to the section of road *d* towards *e* is made up of the distances, 2 miles from quarry to *d* + half the distance to dividing line, which equals ·345, or a total of 2·345 miles. This average mileage at 7¾d. amounts to 18·17d. per ton.

Summarizing these items, the total price per ton for the whole operation on the portion of the section of road from *d* towards *e* is obtained.

Quarrying, breaking, and rolling, . . .	28·00	per ton.
Scarifying, forming, etc., 0·22d. per sq. yard × 14, .	3·08	,,
Haulage, ...	18·17	,,
Pence,	49·25	,,

or 4s. 1¼d. per ton consolidated.

The length of the road to be supplied from the quarry *b* is 1214 lineal yards, and as 1 ton of metalling spread close will (according to the rule) cover 14 square yards of road, the quantity of metal required is found to be 404 tons. The total cost of this quantity of metalling, at the price given above, is £82, 18s. 1d. The remaining portion of this section, extending to 546 lineal yards, is arrived at in a similar manner, the quantity of material being 182 tons.

The price per ton for all these items, except the haulage, is the same as in the previous case, namely, 31·08d. The conveying of the metal a distance of 2 miles + ½ of 0·31 miles, or 2·16 miles, at 9d. per ton, costs 19·40d., which is an inclusive price of 50·48d., or 4s. 2½d. per ton consolidated. The portion of this section, therefore, will cost £38, 5s. 11d., or a total for the section of road between *d* and *e* of £121, 4s.

The other sections, *e* to *f* and *f* to B, are proceeded with in the same manner as section *d e*, the dividing line on the former portion being distant 1073 lineal yards from *e*, while the distance from the dividing line to *f* is 2235 lineal yards.

Having thus ascertained the point on the road at which the metalling from the respective quarries *b* and *c* should join, so as to equalize the price for haulage, the cost of the whole work can be estimated.

As the old metalling on this portion of the road contained a considerable amount of small stuff and detritus, it was decided to scarify and screen the material before applying the new coat of road metal. The scarifying, taking it at 0·10d. per square yard, will, allowing 11 square yards for 1 ton of macadam 3 inches thick, cost 1·10d. The screening, including repairs to tools, may be easily performed for 0·27d. per square yard; this is 3d. per ton, calculated on the material which is to form the new coating, making an inclusive price for this work of 4·10d. per ton. Therefore, taking the cost of quarrying, breaking, and rolling as already stated, the total cost is 32·10d.

The average cost for haulage on the portion of the road nearest *e*, at 9d. per ton-mile, is 20·75d. per ton, which, added to the previous items, amounts to 52·85d., or 4s. 5d. per ton of metalling consolidated. The quantity of material required for this portion of the road is, for a width of 18 feet, 586 tons, and the cost £129, 8s. 2d. The remaining portion of this section, extending to 2235 lineal yards, requires 1219 tons to form a coat 3 inches thick and 18 feet wide. The average cost for haulage on this portion of the road is 18·52d. per ton, which, added to the other items, gives 50·62d., or 4s. 2¾d., as the cost per ton of macadam consolidated.

The expenditure for repairs on this part of the road is therefore £257, 15s. 4d.

In regard to the last section of road *f* B, the dividing line is easily arrived at, being the half-distance between the points *f* and B. This averages 2·25 miles from the quarry *c*, which, at 7¾d. per ton-mile, amounts to an average cost of 17·44d. per ton.

TABLE

County of.....; .....

Probable Estimate of Road Rolling,

Division.....from A.....to B.....

Mileage of Road to be Rolled.	Description of Road.	Name of Quarry from which the Material is to be taken.	Cost for Quarrying, Breaking, Scarifying, and Rolling.
Miles 1·12	From, etc., A to *d*,	*b*	Quarrying, . . . 7·50 Breaking, ... 12·00 Rolling, ... 8·50 Pence, . . 28·00
0·69	From, etc., *d* to dividing line in direction of *C*,	*b*	Quarrying, . . . 7·50 Breaking, ... 12·00 Scarifying and forming 0·22d. × 14, . . . 3·08 Rolling, ... 8·50 Pence, . . 31·08
0·31	From, etc., dividing line to *e*,	*c*	Quarrying, etc., same as above, ... 31·08
0·61	From, etc., *e* to dividing line in direction of *f*,	*c*	Quarrying, . . . 7·50 Breaking, ... 12·00 Scarifying, 0·10 × 11 = 1·10 + screening = 3·0, . . 4·10 Rolling, ... 8·50 Pence, . . 32·10
1·27	From, etc., dividing line to *f*,	*c*	Quarrying, . . . 7·50 Breaking, ... 12·00 Scarifying, 0·10 × 11 = 1·10 + screening = 3·0, . . 4·10 Rolling, ... 8·50 Pence, . . 32·10
1·00	From, etc., *f* to B,	*c*	Quarrying, . . . 7·50 Breaking, ... 12·00 Scarifying, 0·10 × 8 = 0·80 + screening = 3·00, . 3·80 Rolling, ... 8·50 Pence, . . 31·80
5·00			

NOTE.—One ton of metalling 1 in. thick covers 32 square yards.

XXXVIII.

District or Division.

etc., for Year 1898–1899.

Haulage per ton-mile, and Total Cost per ton.	Width of Coating and Depth of Metalling.	Quantity of Metalling required in tons.	Price per ton consolidated.	Cost of each Section.	Total Cost.
			s. *d.*	£ *s.* *d.*	
2 miles from quarry + ½ distance along road = 2·56 at 7½d. = . . . 19·84 / 28·00	18 feet wide, 4″ thick.	1760 × 1·12 = 1972 × 6 = 11832 ÷ 8			
Pence, . . 47·84		= 1479	4 0	295 16 0	
2 miles from quarry + ½ distance to dividing line = 0·345 = 2·345 at 7½d. = . 18·17 / 31·08	14 feet wide, one stone thick.	1760 × 0·69 = 1214 × 4⅔ = 5665 ÷ 14			
Pence, . . 49·25		= 404	4 1¼	82 18 1	
2 miles from quarry + ½ distance to dividing line = ·155 = 2·135 at 9d. = . . 19·40 / 31·08	14 feet wide, one stone thick.	1760 × 0·31 = 546 × 4⅔ = 2548 ÷ 14			
Pence, . . 50·48		= 182	4 2½	38 5 11	
2 miles from quarry + ½ distance to dividing line = ·305 = 2·305 at 9d. = . . 20·75 / 32·10	18 feet wide, 3″ thick.	1760 × ·61 = 1073 × 6 = 6438 ÷ 11			
Pence, . . 52·85		= 586	4 5	129 8 2	
1·75 miles from quarry + ½ distance to dividing line = ·64 = 2·39 at 7½d. = . 18·52 / 32·10	18 feet wide, 3″ thick.	1760 × 1·27 = 2235 × 6 = 13410 ÷ 11			
Pence, . . 50·62		= 1219	4 2⅝	257 15 4	
1·75 miles from quarry + ½ distance along road = 0·50 = 2·25 at 7½d. = . 17·44 / 31·80	18 feet wide, 4″ thick.	1760 × 1·00 = 1760 × 6 = 10560 ÷ 8			
Pence, . . 49·24		= 1320	4 1¼	270 17 6	
	Total for Division..... from A..... to B.....				£1075 1 0

The depth of fresh metalling on this section was increased by 1 inch to give a proportionately greater strength to carry the additional traffic from the road towards the quarry *c*. This affected the cost of scarifying compared with the section *ef*; one ton of metalling covering an area of 8 square yards at a depth of 4 inches, so that the cost of scarifying calculated on the new material, 0·80d., and the expense of screening brings this item up to 3·80d. per ton.

The different items summarized amount to 49·24d., or 4s. 1¼d. per ton of metalling consolidated.

The quantity of material required for a width of 18 feet and of the thickness mentioned is 1320 tons, which amounts to £270, 17s. 6d. for this section.

The total cost of repairing the different sections of road from A to B amounts to £1075, 1s., being at an average rate of £215 per mile.

The arrangement and method of calculating the cost of performing the work has been given in detail, so that the different items may be easily followed; it is usual, however, to make the estimates for this work in a tabulated form, which should be preserved for future reference.

The foregoing form (pp. 282, 283) is that adopted by the author, experience having proved the efficiency of the method; a sketch plan of the roads to be repaired should form a part of the arrangement as shown in fig. 120.

391. Cost of Light Repairs.—The cost of scarifying a road 5 yards wide, raking the materials into a proper contour, and rolling, without applying any fresh materials, will cost on an average from £25 to £30 per mile. It is a very significant fact that, when repairing roads by this means, and where the metalling has been consolidated by wheel traffic, owing to the excessive quantity of small or exhausted material, a large amount of detritus is produced in rolling-in the old material again, which should be swept to the sides of the road. In many cases the surplus of soft or useless material, beyond that required for binding in connection with refacing the surface, amounts to 30 per cent. of the bulk of old metalling operated on.

This large amount of fine stuff or detritus is accounted for by reason of the high proportion of soft to hard material composing the crust of a road when the repairs have been carried out by spreading the metalling in patches, and allowing it to be consolidated by the wheel traffic.

It is also augmented by the wear of the material itself, the stones in course of time being reduced in size, and pulverized by the abrasion of the wheels of vehicles during the process of consolidation.

On rolled roads, when refaced to improve the surface, where the material used has been of a good quality, the amount of detritus is generally just sufficient to form a binding during the process of rolling-in the metalling.

In the case of a narrow road when, as too often happens, the traffic keeps one track, the surface of the road immediately under the line of the wheels

becomes depressed, or is worn hollow. To repair a road in this condition it is only necessary to run two cuts with the scarifying machine on either side, and sprinkle some fresh metalling on the loosened portions, and with watering and rolling a hard surface is obtained.

The cost of this work, including metalling at 4s. per ton, is £7 to £10 per mile.

392. Old and New Systems of Maintenance Compared.—The different methods of performing the repairs necessary to maintain a road in good condition have been described, and the cost of carrying out the work detailed. It is now necessary to make a comparison from a financial point of view between the old system of spreading the metal in patches and forcing the wheel traffic to consolidate the macadam, and the method of coating to a full width long stretches of a road, and consolidating the metalling by steam-rolling.

Three different cases, among many others, taken from the author's experience, and which are typical of what is met with in daily practice, will be given of roads under varying conditions of traffic and quality of material used for repairs.

(*a*) In the first case the road, previous to being rolled, was repaired with a hard siliceous material over which passed a considerable amount of traffic, principally agricultural, and confined practically to a few months during the winter season. On an average, spreading the amount of traffic over the twelve months it is equal to 4000 tons per yard of width of road per annum. This road may be characterised as being situated on easy gradients with good surface and subsoil drainage—in other words, a particularly well laid out road.

(*b*) In the second case, the road was repaired with macadam of a highly siliceous nature previous to being rolled. It is for the most part comparatively level longitudinally, resting on a stratum of retentive clay; consequently the drainage is sluggish. The wheel traffic passing over this road is equal to 5000 tons per yard of width of road per annum, and is fairly well divided between the winter and summer months.

(*c*) The third road under review has a gentle undulating surface throughout, while the traffic over it is light and principally confined to the summer months. It was repaired with metalling of a nature varying from hard and tough to that of a highly siliceous composition.

(*a*) The cost of maintaining this road, carried out by patching, taking the average annual expenditure per mile over a period of ten years, was as follows:—

Labour, including spreading the metalling, siding, scraping, cleaning, etc.,	£24	2	0	
Metalling (hand broken),	32	1	8	
Total,	£56	3	8	per mile.

The annual consumption of macadam was, taking the average over a similar period, 140 cubic yards or 155 tons per mile, and the cost of metalling deposited in depôts at roadside on an average 4s. 7d. per cubic yard. The relative cost of labour and material to the combined expenditure was, therefore, 41 per cent. in the case of the former, and 59 per cent. in that of the latter.

The roadway is 18 feet wide between the sod borders, but only 15 to 16 feet of metalling constitutes the road proper.

A cubic yard of ordinary 2½-inch gauge metalling, including the small material inseparable from unscreened hand-broken macadam, will cover an area of from 27 to 31 square yards according to the proportion of small stuff to the maximum sized stones, but 29 square yards may be taken as an average. The number of square yards covered per annum was therefore 4060, which is nearly one-half of the total area of the surface on one mile of road.

A portion of this road was repaired ten years ago by a continuous coat of metalling 14 feet wide and steam-rolled. The material for carrying out the repairs was taken from the same quarry; consequently the quality in either case was practically the same. The average thickness of the coating was 3 inches, the quantity of metalling applied being 780 tons per mile, or five times the annual quantity previously applied on the patching system.

The cost of carrying out this work, including quarrying, breaking the macadam by machine, haulage by team labour and consolidating the metalling by steam-rolling, amounted to £156, 14s. 3d. per mile, or nearly three times greater than the sum previously expended annually. This is at the rate of 4s. per ton of material consolidated.

The coating, as already stated, averaged 3 inches in thickness and had a life of eight years; it was then found necessary to reface it as the surface had become cupped and irregular.

This was effected by scarifying a width of 12 feet in the centre of the road, applying 200 tons of metalling per mile, and rolling; a good hard, smooth surface was obtained.

The refacing cost £42, 10s. per mile. The road is in excellent condition at the present time, and, judging by past experience, one is safe to anticipate that it will wear for another two years before further repairs are necessary.

The total cost for repairs up to the present time has thus been £199, 4s. 3d. per mile, to which sum has to be added the manual labour for surface work during these years, such as trimming the borders, cleaning the side channels, and scraping. The actual expenditure for this work, on an average, amounts to a fraction under £7 per mile per annum, which is equal to £70 for the ten years this section of road has been rolled, and, adding the cost of the first rolling and the refacing, the total is £269, 4s. 3d. The annual expenditure during these years has therefore been £20, 12s. 11d.

per mile, showing a saving on this portion of road of 63 per cent. each year. This amount is exclusive of interest on the initial cost of remaking the road, as the saving effected after four years more than compensated for this charge.

(*b*) The annual expenditure on this road, taken as in the preceding case over a similar period, namely, ten years previous to coating and rolling, was on an average £74, 18s. 6d. per mile. The quantity of metalling applied each year was 208 cubic yards or 231 tons per mile, the price of which, laid down in depôts at the road-side, was 4s. 11d. per cubic yard. The respective figures for maintenance per mile per annum were as follows:—

Labour, etc.,	£24 0 0
Metalling,	50 18 6
Total,	£74 18 6

These two items, therefore, bore a proportion to the combined cost of 68 per cent. for road metal, and 32 per cent. for manual labour.

The width of the roadway varies from 15 to 18 feet, while 16 feet may be taken as representing the average width, so that with the quantity of metalling stated, fully 64 per cent. of road surface was coated each year.

This road was repaired and steam-rolled five years ago; the actual quantity of metalling applied was 826 tons per mile, which is an average thickness of 3 inches for a width of 15 feet.

It will thus be seen that, for continuous coating and rolling operations, the quantity of metalling applied was equal to nearly $3\frac{3}{4}$ times the annual supply found sufficient to keep the surface of the road in good repair.

The quality of the material forming the coating to be steam-rolled was not equal to that which was formerly applied for patching.

The quarry from which the material was usually procured for repairing this road is situated six miles distant, and the transport could only be done by team-work. It was, therefore, decided to obtain the metalling from some other source as a matter of economy in first cost, but, as will be shown later, this was an unfortunate arrangement, having regard to the cost and the ultimate wearing capacity of the macadam used. The material used was brought ten miles by rail and broken by the machine at a railway depôt within $1\frac{1}{2}$ miles of the road to be remade.

The cost of coating and rolling this road, including freight and all other charges, was £213, 18s. per mile, or nearly three times as much as the previous annual expenditure. Owing, however, to the metalling not being of so durable a nature as that formerly employed for repairs by patching, the surface of the road became irregular or cupped three years after being repaired. It was considered necessary to scarify and to apply a coat of metalling after the material used in the first repairs had served for

four and a half years. This re-facing cost £91, 3s. 7d., while the quantity of macadam applied was 266 tons per mile. The inclusive cost for the two operations was therefore £305, 1s. 7d. per mile of road repaired.

At the present time the surface of the road is becoming so much cupped that it will be necessary to thoroughly repair it in the course of a year or two, by scarifying and screening the old material, applying a fresh coat of metalling of a more durable nature, and rolling so as to bring about a more satisfactory state of matters.

The quantity of road metal, therefore, which has been applied for consolidation, being 1036 tons per mile, and assuming the time mentioned as that when further repairs will probably have to be carried out, the road will have had a life of only six years.

It has consequently cost besides interest £50, 16s. 11d. per mile per annum for metalling and rolling, to which sum has to be added £17, 5s., being the actual amount expended for surface labour, or a total of £68, 1s. 11d. per mile per annum. This amount, even under the adverse circumstances mentioned, shows a saving for this method of executing repairs of 9 per cent. over the patching system of maintaining roads. Had a more suitable material been employed in the first instance, the probability is that the surface of the road would have withstood the wear of the wheel traffic for as long a time as the combined operations have lasted. It would also, it is confidently assumed, have been the means of greatly reducing the ultimate total amount of expenditure incurred.

(*c*) In the third case referred to, the wheel traffic was of a light description and principally confined to the touring months in summer, the annual consumption of metalling, which was of a good quality, being on an average for a similar period as in the preceding cases 35 cubic yards or 39 tons per mile per annum, while the actual expenditure on maintenance for a like distance and time was £13, 15s. 6d.

The proportion of the material and labour to the combined cost was 51 per cent. for the former, and 49 per cent. for the latter, the price of the macadam being 4s. per cubic yard deposited in depôts at the road-side.

This line of road, over ten miles long, was coated with metalling and rolled ten years ago, and re-surfaced three years since, so that the first coating, a light one, and rolling had a life of seven years. The quantity of material then applied for rolling was 350 tons per mile, or equal to nine times the average annual supply previously used for repairs.

The actual cost of supplying the metalling from three different quarries which were situated within easy distance of the main road, and rolling, was £62 per mile. The metalling and rolling was thus equal to £8, 17s. 2d. per mile per annum, and adding the expenditure actually incurred for manual labour in dressing borders, scraping, etc., amounting to £3, 15s., made a total of £12, 12s. 2d. per mile per annum. This shows an apparent saving

FIG. 121.—Fifteen-ton compound road-roller (Aveling & Porter's) working on road. [*To face p. 289.*

of 8 per cent. on the previous annual expenditure, but as an allowance must be made in this case for interest on the initial cost of rolling, the actual saving is only 4 per cent. The reduction of expenditure, although small, combined with the indirect saving to horses and vehicles by reason of the hard and smooth surface which the road presents all the year round, is a distinct advantage. It is also a sufficient plea for carrying out rolling operations even when the annual consumption of materials for repairs, by the old or patching system, only amounts to 35 cubic yards per mile of road.

393. Conclusions arrived at from the preceding Comparisons.—From the particulars stated in the preceding paragraphs, referring to the cost of repairs on existing roads under different conditions, it is evident that maintaining them on the principles advocated, namely, obtaining the materials and performing the work by the use of modern mechanical appliances, spreading the metalling in continuous coatings and steam-rolling, provides a road not only uniform and smooth, but one which is equally good and serviceable at all times. The comparative absence of loose stones, dust in dry weather, and mud after a fall of rain, greatly reduces the tractive efforts required by horses hauling loads, and these conditions are of considerable moment to all who have occasion to use the highways. The economy of the methods of working enumerated in the preceding chapters (the results of which have been pointed out in detail) are, the author considers, conclusive, even on roads where the necessary annual outlay or the quantity of metalling used on the patching system is relatively small. When these methods of repairing roads are more fully appreciated, the system of laying isolated patches of metal and compelling the traffic to consolidate them, a system which is so well known, so largely practised at the present time, and so expensive and unsatisfactory in its results, will be discarded entirely for the more modern methods of consolidating the material by the aid of steam rollers only. Fig. 121 illustrates Aveling & Porter's most recent design of their 15-ton compound road-roller.

394. The difference in first cost, compared with the ultimate economy and success of the work, by using a suitable class of material, compared with that of employing an inferior class of stones obtained locally, warrants most careful consideration. Experience has proved that the cheapest material is not always to be recommended, as quality, although involving greater cost by reason of the longer haulage, is of more importance; and the ultimate durability and economy of maintenance may be secured by employing only the best material which can be procured.

395. Surfacing Roads.—The manual labour in connection with the maintenance of the surface of a road consists of scraping the surface during wet weather, siding, cleaning side and outlet channels, repairing footpaths, etc., the labour connected with which is augmented when the material for

repairs is spread in patches to be consolidated by the wheel traffic, and gathering loose stones during dry weather.

The cost of these two latter items amounts to on an average 1s. 3d. per cubic yard in cases where over 50 cubic yards are applied per mile per annum, to 1s. 6d., when the average quantity is under that stated. These figures are, however, at times considerably augmented under abnormal conditions of weather and other causes.

The annual cost of manual labour per mile in the three instances already detailed, previous to the roads being repaired by continuous coatings of metal and steam-rolled, and the subsequent actual expenditure for surface work, may be here tabulated.

TABLE XXXIX.

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when the roads are repaired in patches, depends on the quantity of material applied each year and the situation of the road. Where the annual consumption of metalling is from 200 to 300 cubic yards per mile, one foreman can generally attend to 3 miles of road, receiving assistance when spreading the macadam and in scraping the surface during inclement weather. The length of section may be increased to 5 or 6 miles when the annual consumption of materials is about 40 cubic yards per mile. On rolled roads where the repairs are carried out on the continuous coating principle, the length of the section under the charge of one foreman can be extended to 6 or 8 miles when it is made up of portions of different roads lying in convenient proximity to each other. The foreman should be constantly employed on his section of road during the winter months and in wet weather, but during the summer months his services, not being required in most cases for surface work, may be available in connection with the rolling or breaking operations—an occasional visit, especially after a rain-storm, being all that is necessary under these improved conditions in summer. The loose stones requiring to be removed from the road surface during dry weather when the repairs are carried out on the patching system, unless consolidated by the steam-roller, occupy the roadmen's time to a considerable extent. On roads which have been efficiently rolled, loose stones are the exception; indeed many roads require no expense whatever in respect of this.

398. Tools required for Surface Work.—The tools which each foreman roadman should have, are a shovel, spade, line and reel, pickaxe, barrow and a hand-machine scraper, extra spades and shovels being necessary when casual labour is employed. The spirit-level and boning-rods formerly used by the ordinary roadmen are now employed only by the foreman in connection with the rolling operations. These are even dispensed with when a thoroughly experienced man is in charge of the work, except in forming new water tables or channels, a good eye being in most cases a sufficient guide in carrying out the work.

A hand-scraping machine should be provided on every roadman's section, and when the extent of the roads looked after by one man exceeds 4 or 5 miles, or the exigencies of the traffic and situation of the road demand it, two or more machines should be provided.

These machines, although not intended for constant use on rolled roads, supplement the work done on certain portions of it by the horse-scraping and sweeping machines. On a road which is repaired on the patching system, or when the surface of a road becomes cupped through irregular wear, the hand-scraper is the only form of machine that can be advantageously employed.

To maintain a road in a good and hard condition it is necessary to remove the detritus resulting from the wear of the metalling. This is generally

in the form of mud; although dust is sometimes removed from the roads, but this is only practised to a limited extent.

To be a substantial advantage the scraping of mud off the road should be done promptly when the weather is favourable for the work.

The detritus being on the surface of the road and increasing in quantity during wet weather, evaporation is prevented and considerable damage is caused to the crust of a road in the event of a sudden thaw succeeding frost.

The weather during the winter months is generally so changeable that continuous or extensive operations with the hand-scraping machine are limited.

It is very desirable, not only for those making use of the roads, but also for the benefit of the road itself, that any mud formed on the surface should be immediately removed by scraping or sweeping.

The short working day inseparable from the time of the year when these operations are carried out does not admit of much work being performed, while to employ extra men specially would incur a considerable expenditure.

399. Horse-Scraping and Sweeping Machines.—A long stretch of road is cleaned in the shortest possible time by employing horse-scraping and sweeping machines. The former is used when the mud or detritus is in a sticky condition, while the latter is employed when the mud is in a liquid or semi-liquid state.

These machines are constructed so that the scrapers or brushes are mounted on the framework oblique to the direction in which they are drawn; they clean a track about 6 feet in width, and the mud is deposited at the sides of the road. The framework is a combination of oak and wrought iron, the shafts being made of ash, while the wheels in the case of the sweeping machine are made with iron naves, oak spokes, and ash felloes. The wheels of the scraping machines are made of wrought iron; they are 3 feet 9 inches in diameter, while those of the scraping machine are 4 feet 9 inches.

The hoes or shoes of the scraper are made of cast iron and can be easily renewed, means being provided for regulating the tension of the springs so as to give them the desired pressure on the road. The sweeping machine is provided with double clutch gearing which imparts the motion to the circular brushes. They are provided with a driver's seat, and the levers for manipulating the mechanism are within easy reach, avoiding the necessity of the man dismounting or even stopping the horse while working the machines. Oil-cups properly protected with lids are provided for lubricating the working parts.

To minimize the scraping of roads during the winter months when the working days are of short duration, it is advisable to make use of every opportunity during the autumn and the beginning of winter for scraping

the surface of the roads and cleaning out water tables, side channels, and ditches.

400. Alternating frost and thaw will at times frustrate the best regulated system of maintaining roads, and it is only by exercising patience, and making use of the appliances at hand at the proper time, that the best results will be attained under these circumstances. In cases where the humidity of the atmosphere, in the absence of rain, causes the mud to become very sticky, great difficulty is experienced in removing the detritus from off the roads. Under such circumstances it is advisable, where a supply of water can be obtained, to water the surface copiously, and then commence scraping with the horse machine.

In cases where the mud, even with this treatment, remains sticky, the author has obtained good results from watering the road and working the road-roller over the surface; by this means the thick mud is converted into a semi-fluid state, when it can be easily removed by the horse-scraping or sweeping machine.

The road scrapings should be removed from the water tables immediately after being deposited there by the scraping or sweeping machines, or, when in a semi-liquid state, as soon as they are in a condition to be shovelled, so as to admit of the surface water draining freely into the side channels.

Scraping should not be attempted immediately after a thaw succeeding frost, as the surface of the road is then tender, and the stones are easily displaced.

401. Amount and Cost of Work which can be performed with Hand and Horse-Scraping Machines.—The cost of scraping a road with a hand machine will, of course, depend greatly on the amount of detritus to be removed and its condition. When in a soft or pliable state, and from $\frac{1}{2}$ to $\frac{3}{4}$ inch thick, one man can, on a road of about 5 to 6 yards wide, thoroughly scrape about one-fourth of a mile in a day, being equal to an area of 2200 square yards, or nearly half an acre.

This is, under the conditions stated, at the rate of 12s. per mile of road. The cost of performing the operation with a horse-scraping machine on a similar length and width of road, including repairs and depreciation, is on an average 2s. to 3s., depending on the thickness and condition of the mud.

The length of road which can be scraped in one day of seven hours with a horse machine may be taken at 3 miles, where the width is such as to require from four to six passages of the scraper. The work which can be performed with a horse-scraping machine is, taking the exigencies of the traffic into consideration, on an average about 4500 square yards per hour.

The extent of surface which can be cleaned in one day with a horse-

sweeping machine may be taken at about 50 per cent. more than that which can be cleaned with a horse-scraper or about 4½ miles of road of an average width of 16 feet.

402. First Cost of Hand and Horse-Scraping Machines, and Repairs.—The first cost of a hand-scraping machine of the usual type, mounted on iron wheels with steel hoes or shoes, is from £3 to £4, and the number required in country districts is on an average one for every 3 or 4 miles of road.

A horse-scraper of the class described, and constructed by the Messrs. Wadsworth, Halifax, costs from £19 to £24. The renewals are confined principally to the hoes or shoes, which wear unequally, necessitating their position being rearranged occasionally, and practically renewed every three or four years according to the amount of work performed. A complete set of these scrapers or shoes, twenty-seven in number, costs 35s., including time for fixing them on the machine.

The cost of a horse-sweeping machine varies from £30 to £35, the wearing parts being more numerous than those of a horse-scraper. The bass of the revolving brushes requires renewing periodically as it is worn out. On an average a new set will be required after sweeping a stretch of 400 miles. The cost of refilling the brushes with the best pure Bahia bass mixed with African weed is £2, 2s. 6d., and an equal mixture of these gives the best wearing results.

The chain belt, bearings of brush shaft, brush shaft ends, and knuckle joints require renewing after working about 4000 hours. The cost for these renewals is about 2s. per day of nine hours.

These machines, unlike the hand-scrapers, are operated in the direction of and from the centre to the sides of the road. They are used so as to work in suitable lengths along a road, the mechanism being thrown out of gear when turning, the mud is delivered at the left-hand side of the machine, and by repeated passages the whole surface is cleaned.

The author has found the machines described in the preceding paragraphs of great assistance, especially when the roads are rolled; being light they can be drawn by one horse; they are durable and easily manipulated.

On an average one horse-scraper and one horse-sweeping machine are sufficient to keep the surface of 100 miles of road clean, provided they are 'stabled' centrally in the district where it is intended to use them. The work may have to be supplemented, however, by hand-scraping on isolated portions of a road which are badly situated, or where hedges or close fences obstruct the sun and wind, and hinder the road from drying.

403. Road-Edge Dressing Machine.—This machine, which has recently been introduced, is the invention of the County Road Surveyor of Elgin. It is attached to a road-roller or engine, and is intended to supersede the various kinds of ploughs and other contrivances drawn by animal power,

FIG. 122.—Road-edge paring machine (Hogg's patent). [*To face p. 295.*

which have been devised from time to time. The machine can pare or dress the edges of public roads; the portion trimmed at one operation may vary from 6 inches to 30 inches in breadth, while it can be adjusted to cut from 1 inch to 10 inches in depth.

Besides having a suitable framework it is made up of a revolving cutting steel wheel, 2 feet in diameter, which acts in a vertical direction on the turf border to be dressed. The horizontal cutting is performed by a set of blades or cutting tools; the whole apparatus being regulated by suitable gearing, controlled by a man operating two handles placed on the platform at the rear end of the engine. The edge-dressing machine is attached to an engine or road-roller, as shown in fig. 122, one of the driving-wheels of which acts as the leading wheel of the machine, so as to give it rigidity for steering and sufficient pressure when at work. Parallel sights are fixed on the engine to guide the driver in preserving a regular course.

The loosened materials are left in a continuous heap along the edge of the road and can be disposed of according to circumstances. It is a very efficient machine and does excellent work; it is capable of cutting tree roots of moderate size, rank vegetation, and of penetrating stony ground.

It is stated that by the use of this machine, attached to a six horse-power engine, 15 to 18 miles of road can be pared in one week, including the usual stoppages and changing from one part of a district to another.

It may be worked by an engine hired for the purpose, but is generally attached to a road-roller, thus utilizing the spare time should the amount of rolling be insufficient to so employ it all the year round.

The cost of paring a road-side by the machine is 7s. to 10s. per mile compared with £2 to £4 by hand labour. The price of this road-edge cutting machine fitted on to an engine or road-roller is about £90.

404. Engine and Store Shed.—In a county or district possessing a road maintenance plant, comprising roller, road-engine, stone-breaker, rock drill, sweeping and scraping machines, a shed is necessary to stable the different machines when not in use or when under repair. The shed should be commodious but not unnecessarily large, and have sufficient headway to admit of the free passage of the engines.

One side may be occupied by a working bench with vice, etc., for carrying out small repairs, storage for new tools, and a suitable arrangement for placing the oil casks in position. On the other side of the shed the india-rubber tubing, iron pipes, drill steels, etc., can be stored clear of the ground. A stove fixed at one end is a great convenience in many ways. It is advisable to have adjoining the shed for storing drain pipes and other material, a small piece of ground, and which can also be utilized for stabling the plant temporarily.

A shed to accommodate all the plant used in connection with a district extending from 100 to 200 miles of road will be best served by making it

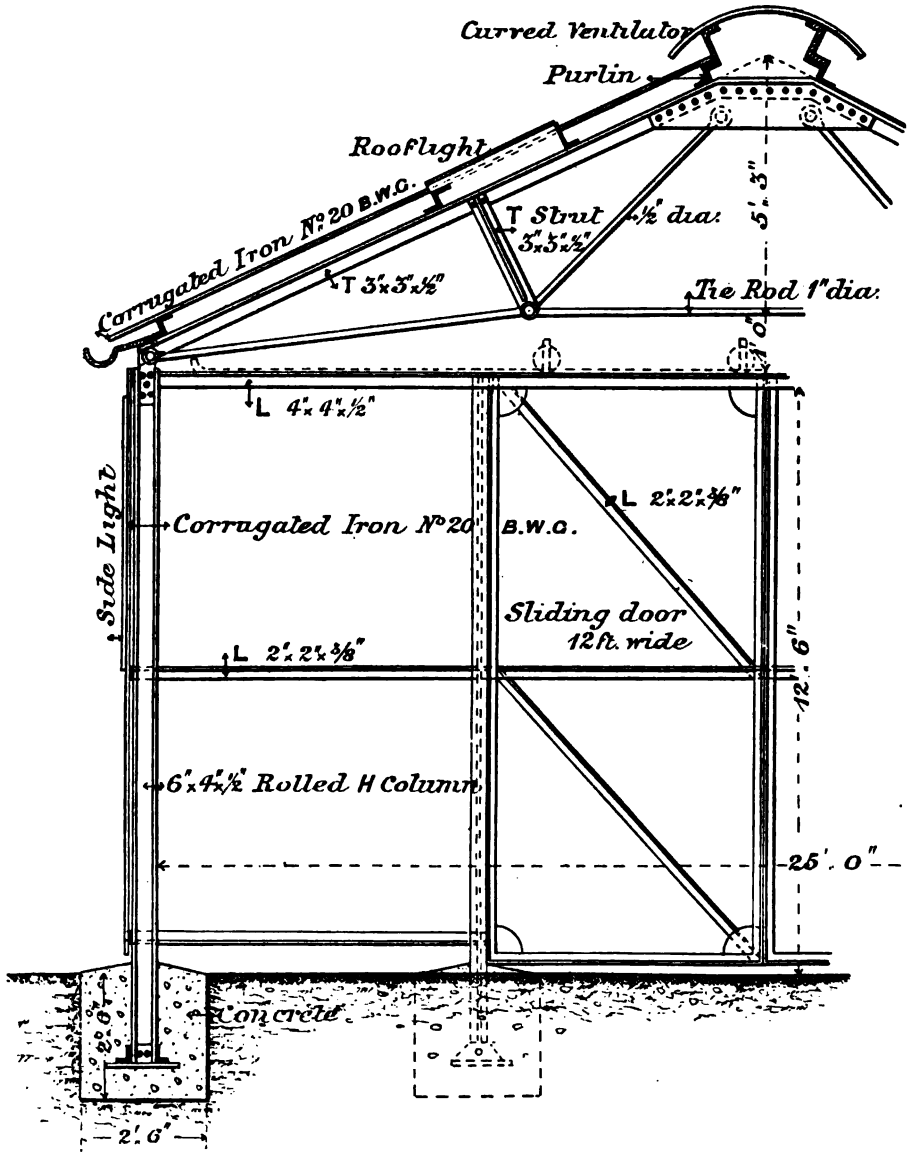


FIG. 123.—Cross-section of engine shed.

about 60 feet long and 25 feet wide; a cross-section of such a shed is shown in fig. 123.

The columns or standards are generally made of channel iron or H-section fixed at their lower ends in a concrete block, and having the top part bolted to an angle iron run round the whole erection.

The doors, 12 feet wide, are arranged to slide by means of wheels on a T-iron fixed to the framework. The roof is made up of T-iron principals, having struts and ties, placed over the standards and fixed to the angle iron by means of a gusset-plate.

The covering is usually of corrugated iron, and of No. 20 B.W.G. fixed to angle-iron runners on sides of shed, and to the T-irons of the roof principals or to purlins. The sheets should be properly lapped, and secured with bolts, washers, and nuts. It is desirable to have as much light as possible admitted to the interior of the shed, and for this purpose windows are fixed either in a continuous manner, or detached, on either side of the shed to the framework. Roof-lights should also be introduced at convenient points.

A space at the apex of the principals is left open for ventilation, and a hood erected over it to prevent the ingress of rain or snow.

The appearance of the erection is greatly improved, and the corrugated iron, although galvanized, is preserved by being painted.

405. Cost of Erecting an Engine Shed.—The cost of erecting a shed of the dimensions given, and of the materials described, may vary from 1s. 6d. to 1s. 9d. per square foot of area occupied, or from £120 to £130, with an additional £5 for erecting benches and other internal fittings. It is advisable to enclose the ground occupied by erecting a fence, the cost of which is not included in the figures given.

406. In addition to having a central shed, small sheds or huts should be erected at convenient points throughout the district, for keeping those of the roadmen's tools which are not in daily use. They are also very convenient for storing coals in connection with rolling operations, as in many districts the sources of supply or the railway depôts are situated at a considerable distance; in many instances they will save considerable inconvenience and loss of time.

If these huts are made of a sufficient size a considerable quantity of fuel can be stored, to supply the requirements in case of emergency. They need not be expensive erections, and may be made either of old railway sleepers or with wood posts, and covered with corrugated iron sheets, at an outlay of from £8 to £12.

407. Purchasing Tools and General Stores.—The purchasing of tools, oils, coals, blasting explosives, and detonators, demands careful attention. If the workmen's tools are obtained locally and in small lots, owing to the want of a proper place to store them, it is evident that the cost of procuring these articles is greatly increased, beyond what would be that of purchasing in large quantities for one or two years' requirements. The supplying of the

necessary tools and stores by contract, and delivering them at one or more convenient points in a district, tend to promote economy, and the saving effected in two or three years will be sufficient to pay for the expenditure incurred in erecting sheds and huts for this purpose.

The month of January is the most suitable and generally the most economical time to purchase tools, oils, etc.; while the contract for supplying coals for the rollers and road-engines should be made in the month of March each year.

In the author's experience the saving effected by purchasing the different articles by contract annually has been 33 per cent., compared with the system formerly practised of procuring the tools and other stores as necessity arose.

408. Rules and Regulations for the Guidance of Roadmen.—Printed rules and regulations should be issued for the guidance of roadmen as to the hours of labour during the summer and winter months, the procedure to be followed in the event of a breakdown or failure of any of the subsidiary works, such as drains, culverts, bridges, embankments, etc., and the arrangements necessary to cope with a fall of snow.

These need not be of a voluminous nature, as long rules only lead to confusion, and are in most cases of little practical advantage; efficient supervision is the only way to attain the maximum results.

The regulations for the Cantonniers on the national roads in France are of a very comprehensive nature, but, apart from these, the supervision is carried out in a thoroughly systematic manner.

On roads which have been rolled, the surfaceman's work is principally confined to siding, cleaning out channels and ditches, repairing footpaths and occasional scraping, while his services may be requisitioned during the summer months at the quarrying, breaking, or rolling operations. It is not advisable to perform the work of surfacing by contract; and as the road foremen and casual labourers are paid by day's wages, the division of roads into lengths makes it easy to compare one man's work with another's when a system of close superintendence is carried out.

In districts where a fall of snow generally takes place each winter it is necessary to provide snow-ploughs to effect such a clearance as will facilitate travelling. These consist of planks fastened together in the shape of a V, 22 inches deep and shod with an angle iron on the lower edge and $\frac{1}{4}$-inch iron plates at the apex, properly stayed in the centre and outer ends, with provision in front for attaching the means for hauling it by horses. The usual size made is from 10 to 12 feet long and 8 feet wide at the extreme end. These are of little use in heavy drifts, which must be cut through by the roadmen with the assistance of extra hands when necessary.

409. Footpaths.—Footpaths alongside roads leading from one town or village to another are of considerable public importance, and require to be

kept in an efficient state of repair. They should be formed of hard materials affording perfect drainage and finished with fine gravel, furnace cinders, or screenings from the breaking machine. In populous places it is advisable to form footpaths of a much more permanent and satisfactory nature, for which purpose tar concrete and similar suitable materials are made use of. The object to be attained is to make a perfectly dry and serviceable path during wet weather, when other parts of the roadway may be in a sloppy condition.

410. Milestones and Direction Boards.—Milestones indicating the distance between important towns generally exist on most of the main roads in Britain. These are now supplemented by guide or direction boards fixed to posts and placed at all important points, such as where one road branches off, or where one road intersects another. These may be made with one or more arms on which the mileage to villages and towns on either side is indicated, while in some instances the elevation of the road above sea-level is also added.

411. Annual Estimates and Actual Expenditure of Road Repairs.—The annual estimates of the cost of road maintenance should be made in detail, showing the allocation of the metalling, the number of cubic yards or tons per mile of road, the price per cubic yard or ton, the cost of manual labour, rolling, and any miscellaneous expenditure, such as bridge and culvert repairs, tools, etc., with the total cost on each section of road.

The actual expenditure incurred should be recorded in detail under the separate heads of metalling, road-rolling, labour, bridges, culverts and drains, tools and sundry items. This may be kept in the form of a diagram showing the cost of the different items of work carried out each year, while the total expenditure, including all these items, should be tabulated on a separate form.

It is usual to construct these 'diagram accounts' with vertical lines, on which the years are marked, horizontal lines being plotted to show the number of cubic yards of metalling applied per mile of road, the cost of this, and also the expenditure incurred for labour, rolling, repairs to bridges, culverts, and other collateral charges. These diagrams are extremely useful for reference, and the history of a road for many years, indicating its capital value, can be seen at a glance. By this means the cost of the maintenance of different roads can be readily compared, and if the system was generally adopted valuable statistics relating to roads generally would be available, so that the annual expenditure for the several items enumerated in different counties of this country could be collated, which would prove very beneficial in forming a comparison, and undoubtedly promote economy and efficiency in management.

PART II.

CHAPTER IX.

CARRIAGEWAYS AND FOOTWAYS.

PRELIMINARY REMARKS—FOUNDATIONS AND PITCHED PAVEMENTS.

412. The method of paving streets and carriageways, which forms Part II. of this treatise, will now be described, beginning with the earlier kinds of material used, such as cobblestones, and finishing with what is now employed in the large cities and towns of this country.

The historical part of this subject, as also the methods adopted in obtaining many of the kinds of material used for paving purposes, but especially in connection with the construction and repairs of macadamized roads by steam-rolling, have been fully explained in the different chapters in Part I. Such matters, therefore, will only be alluded to in the following pages so far as necessary to further elucidate or amplify the subject.

Stone in many different forms has been made use of as a paving material from the time of the Romans, who employed blocks of an irregular shape laid on a foundation of concrete, which presented great solidity and was extremely durable.

The surface of these large blocks, however, does not afford a good foothold for horses, owing to its wearing smooth; consequently this form of paving is not reliable for modern traffic.

Boulder or cobblestone pavements were much used in the towns of this country until they were superseded by a regular pitched paving. Cobbles make a very noisy pavement, and from the irregular shape of the stones it is impossible to joint them closely, consequently the surface cannot be properly cleansed, therefore boulders form an unsuitable as well as an insanitary paving material. Streets in many of the English towns are still paved with cobbles, but these are being gradually replaced by better descriptions of pavement.

The large regular shaped blocks 8 inches wide which were introduced

in more recent years have been gradually reduced in size, the width of the setts now used being generally 3 inches, laid on a foundation of Portland cement concrete.

413. The other materials used at the present time for paving carriageways are wood, asphalte, brick, tar-macadam, many kinds of artificial stone and blocks, and ordinary road metalling consolidated by steam-rolling.

Where the vehicular traffic is very heavy, and the annual cost of maintenance and scavenging consequently high, it is desirable to apply either of the paving materials already mentioned, so as to provide a harder and more durable surface, and construct a more permanent roadway than can be made by the use of ordinary macadam.

414. In this country, authorities on the subject fix the limit for traffic at 40,000 tons per yard-width of road per annum, and for maintenance, including cleansing and watering, at a cost of 2s. per square yard annually for macadamized roads. When these figures are reached, that description of pavement should be adopted which is most suitable to the location of the thoroughfare and the class of traffic passing over it. It should be remembered that certain specific interests have to be considered in dealing with this somewhat complicated question.

The principal points in connection with this are the first cost of construction and subsequent maintenance. The description of material selected should not be unduly noisy or dirty, as this would annoy the residents and injuriously affect business premises and shops adjoining the streets. The interest of owners of horses and vehicles, as they are the principal users of the streets, merits a considerable share in the consideration of the subject. Ease of traction, which means the economical conveyance of merchandise, has to be considered, as has also the immunity from accidents by falls, that is, the comparative safety for travelling. Neglect of these considerations and the consequent damage to horses' legs and hoofs, will necessarily represent a considerable loss of money annually, and attention to them a proportionate diminution of loss.

Economy in the ultimate cost for construction and maintenance is of considerable importance, and affects the ratepayers directly, while noiselessness and absence from dust or mud affect pedestrians, business people and shopkeepers, and, on the other hand, good foothold and smoothness affect all those who own horses and vehicles.

415. Some of the essential features which a good pavement for the carriageways of cities and towns should possess, may be summarized as follows :—

(1) It should be impervious.

(2) It should be suitable for varying gradients and afford good foothold for horses.

(3) It should be durable, moderate in first cost and subsequent annual repairs, have sufficient curvature to throw off surface water rapidly, and be non-absorbent and easily cleansed.

(4) It should be as noiseless as possible.

(5) It should be constructed with a sufficient foundation for the class of traffic which it has to bear, so as not to subside under the influence of heavy loads.

(6) It should present a uniform and smooth surface, so as to render traction easy.

All the conditions enumerated affect those interested in a varying degree; consequently the usual difficulty is to carry out one or two of the essential requirements mentioned without sacrificing the individual interests of many of the inhabitants.

The details referred to affect the several kinds of pavement differently, and will therefore be described under each separate class.

416. A pavement which is eminently suitable for the thoroughfare of a provincial or agricultural town will not, in the generality of cases, be appropriate for the carriageway of a city or manufacturing town where the streets are subjected to a heavy and continuous traffic. Neither the physical features of a town, nor the climate, should be lost sight of in determining the pavement most suitable for a street or carriageway.

As illustrating the effect of traction on some of the different kinds of materials used, the following table, now universally adopted, may be given previous to describing in detail the construction of the several pavements made use of at present for provincial and metropolitan street traffic.

TABLE XL.

Traction on level roads formed of different materials, asphalte being taken as the standard of excellence.

Asphalted roadway,	1·0
Paved roadway, dry and in good order,	1·5 to 2·0
,, ,, in fair order,	2·0 ,, 2·5
,, ,, but covered with mud,	2·0 ,, 2·7
Macadamized roadway, dry and in good order,	2·5 ,, 3·0
,, ,, in a wet state,	3·3
,, ,, in fair order,	4·5
,, ,, but covered with mud,	5·5
,, ,, with the stones loose,	5·0 to 8·2

Another useful table, prepared from experiments made by Mr. Amos on different descriptions of pavement in the city of London, is here given:—

TABLE XLI.

Road Material.	Speed in miles per hour.	Draught in lbs.	Fraction of load.	Tractive force in decimals of the load.
Gravelly macadam in a side street,	6·945	126·6	$\frac{1}{45·3}$	·0219
	3·45	114·322	$\frac{1}{50·3}$	·0197
Granite pitching by side of tramway,	5·15	70·963	$\frac{1}{81·1}$	·0123
	3·196	41·932	$\frac{1}{137·3}$	·0072
	2·557	45·572	$\frac{1}{121}$	·0082
Granite macadam 'freshly laid,'	4·239	262·886	$\frac{1}{21·9}$	·0456
	2·775	242·726	$\frac{1}{23·7}$	·0421
Asphalte pavement,	5·025	91·525	$\frac{1}{64·9}$	·0158
	3·56	69·758	$\frac{1}{82·5}$	·0121
	5·687	84·268	$\frac{1}{68·3}$	·0111
Wood pavement,	3·932	118·163	$\frac{1}{48·7}$	·0205
	3·278	102·412	$\frac{1}{56·2}$	·0177
	3·827	100·066	$\frac{1}{57·5}$	·0173
Macadam road very good on Victoria Embankment,	6·65	109·06	$\frac{1}{52·7}$	·0181

417. Boulder or Cobblestone pavements at one time formed the principal paving, and still exist to a considerable extent in some of the cities and provincial towns in England. They afford a fairly good foothold for horses, but the roughness of the surface makes travelling over them very unpleasant.

This paving, which possesses the merit of cheapness, is easily displaced by the action of the traffic and frost, owing to the irregular shape of the stones, and the inevitable large joints, while at the same time a considerable expenditure of tractive energy is required to move loads over them. For the same reasons it is almost impossible to keep the surface in a clean and sanitary condition.

418. It was found that the increasing vehicular traffic in many of the larger towns entailed a greater cost for maintenance each year, while the discomfort and noise of the boulder pavements, the irregularities caused through wear on macadamized roads, and the manufacture of mud and dust in certain seasons of the year, led to the substitution of a more suitable

class of material in the form of 'cubed granite' or 'setts' for making carriageways and streets.

This class of paving was first introduced into London in 1824 by Telford and laid in Hanover Square, although it is recorded that a pitched pavement was constructed in that city in 1762, replacing an old cobblestone pavement. The stones or setts then used were much larger, compared with the practice at the present time, being generally from 6 to 8 inches wide, 9 inches deep, and 12 inches long.

The earlier pavements laid in London and other towns were constructed in the following manner:—After the soil had been removed to a proper depth and the foundation properly prepared, a substratum of metalling or hard core was spread generally to a thickness of from 9 to 12 inches; in streets, however, which had to bear the heaviest traffic the bottoming was increased in thickness to 15 inches. On this stratum was spread a coating of sand into which the setts were bedded. The principal thoroughfares in London at that period (1828 to 1838) were thus laid, the setts being of Aberdeen granite, 6 to 7½ inches wide and 9 inches deep.

This class of pavement had a life of from fourteen years in Fleet Street to twenty-four years in Cannon Street; the first cost averaged from 11s. to 17s. per square yard, while the amount expended annually for repairs up to the year 1840 was 1¾d. in the former street, and 1d. per square yard in the latter thoroughfare. In the year 1854 the annual cost of maintenance had risen to 3d. per square yard in Fleet Street.

These paving setts when lifted were re-dressed and used again in some subsidiary street where the traffic was not heavy, where they had a further life, which in some instances extended to about fourteen years, making a total duration of about thirty years.

In many cases the paving setts were laid directly on the subsoil, after this had been formed to a proper contour, and the joints were filled with sharp sand or fine gravel.

The dimensions of paving setts were reduced about the year 1850 to 5 inches in width, subsequently to 4 inches, and then 3 inches, which width, with a depth of 7½ inches and a length not exceeding 12 inches, are, with a few exceptions, the standard sizes of paving setts employed at the present time.

The system of laying the paving direct on the prepared ground and even on a loose stratum of hard core, although still followed in many instances, has been gradually superseded by forming the foundation with Portland cement concrete. The thickness and strength of this class of foundation is regulated according to the amount and class of the traffic which has to be accommodated.

419. The 'Euston Pavement.'—One of the first really good pitched pavements made in London was that known as the 'Euston Pavement,'

which was constructed in the following manner:—The ground was formed to the requisite depth and had the same curvature as the surface of the intended roadway was to assume when finished. Upon the prepared ground a coating of coarse gravel was spread 4 inches in thickness and well rammed. On this layer another coat of gravel, mixed with a small quantity of chalk to make it bind, was spread and rammed as in the former case. On this stratum was placed another coat of fine gravel, upon which foundation the setts of Mount Sorrel granite were laid, bedded in one inch of fine sand. The size of the stones was 3 inches square and 4 inches deep, hammer dressed and squared, set close together and laid at right angles to the kerb. The stones were thoroughly rammed by the pavior, the whole surface being finished by spreading over it screened gravel which was allowed to find its way into the joints by the action of the wheel traffic, thereby steadying the whole pavement. The cost of this pavement, including foundations, is stated to have been 12s. per square yard.

420. Width of Carriageways.—The width of carriageways in cities and provincial towns varies according to the requirements and character of the traffic, and may be from 16 feet to 40 feet (being generally a multiple of 8 feet), which is considered ample for vehicles, travelling rapidly, to pass each other safely.

421. The Congestion of Street Traffic.—The congestion in many streets from the enormous expansion of the traffic in the leading thoroughfares of London and other cities is becoming more serious every year. This state of matters has called forth an expression of opinion that new main thoroughfares should be constructed having a width of from 80 feet to 125 feet, diverging in different directions, in order to adequately accommodate the pressure of wheel traffic, which is getting heavier every year and in many instances becoming unmanageable. By such an arrangement the vexatious delays experienced at present would be greatly reduced, if not altogether removed.

The general practice at present in London and in many other large towns, where the wheel traffic is continuous, is to widen the carriageways at the intersections of the streets, which, besides admitting of refuges or resting places being provided for the convenience of pedestrians crossing the thoroughfare, regulates and expedites the movements of vehicles at these points.

Wide streets add materially to the health of the inhabitants, and, in a measure, remove the crowded appearance so common in many old towns, while the greater space between the buildings gives dignity and an air of comfort to the surroundings.

422. Gradients and Contour.—For the purposes of wheel traffic the best form of longitudinal and cross-section would naturally be that of a level line, as any inclination produces friction and consequently additional traction,

and causes wear and tear of horses and vehicles. As, however, the surface water must be drained rapidly from the thoroughfare, especially after a heavy rainfall, a certain amount of inclination, both longitudinally and transversely, is necessary. The contour usually given to a street varies from $\frac{1}{60}$ to $\frac{1}{80}$ of its width, that is, between the kerb on each side, according to the longitudinal gradient, while in many cases a radius of 300 feet is adopted. This latter, on a carriageway 40 feet wide, gives a rise of $7\frac{1}{2}$ inches at the crown, but this is excessive under normal conditions. On this width of thoroughfare a rise of 6 inches is considered sufficient, increasing at points to 7 or 8 inches, where gullies are placed to collect and dispose of the surface water.

The standard contour adopted in Liverpool, where pitched pavements are almost exclusively used, is shown in fig. 123*a*, the rise or versine being fixed at 1 in 48 from the channel to the crown.

The longitudinal section of a street should, whenever practicable, have a gradient of not less than 1 in 120 to 1 in 150 in order to give effective and speedy drainage at the channels; when the gradient is flatter a greater

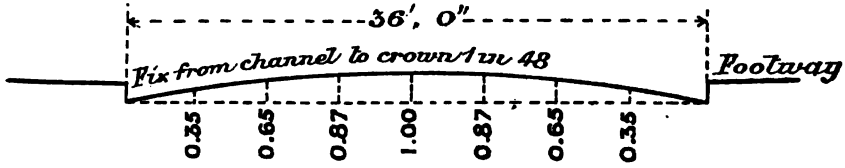


FIG. 123*a*.—Contour adopted for streets in Liverpool.

number of gullies will be necessary to properly discharge the surface water. On very hilly carriageways, owing to the great rush of surface water after a heavy rainfall, more gullies of large capacity are likewise necessary to intercept the water and detritus, compared with streets having only a moderate gradient.

The crown level longitudinally, if at all practicable, should be uniformly maintained from street to street in order to avoid undulations which greatly interfere with the free passage of vehicles.

423. The location of an existing street in a city or town, owing to the topographical features, does not at times admit of a comprehensive system of gradients being established. In villages and suburban districts, which in the course of time may be merged within the boundaries of an adjoining town, the widths and gradients should be adjusted previous to the process of improvements and re-building operations being commenced, which sooner or later will in all probability take place.

The difficulty of obtaining suitable gradients in many cases is very great, especially where an existing building has been erected so as to avoid under-building, the floor level of which may be either too high or too low for any

prospective improvements in the gradient of the street. Excessively deep cuttings or high embankments which, if executed to give a uniform and easy gradient, would naturally affect the value of the adjoining property, may demand steeper gradients than would be permissible under ordinary circumstances.

It should be the aim of those in authority to endeavour to fix a system of gradients convenient for the traffic generally, rather than to consider the interest of any particular individual.

In most instances the work of construction in forming streets is undertaken and carried out by contractors by an offer at schedule prices, so that detailed information as to the different methods adopted by them in executing the work is not considered necessary. The more important operations and other relative matters will be given when it is considered essential to further elucidate the general description of any particular class of work.

424. Formation of Carriageways.—The ground on which the street is to rest is prepared by excavating or making up as may be found necessary to the lines and levels shown upon the plan and section. This applies to both new and the re-making of existing carriageways, except in the case where concrete has already been employed as a foundation, the ground being made thoroughly solid by steam-rolling. When a soft or unsuitable subsoil is met with in the bed of the roadway it should be removed to such an extent and depth as may be found necessary, the voids being replaced with hard sound material. Where it is necessary to embank the roadway, the filling should be done in layers not exceeding 6 inches in thickness, well pounded or rolled, water being applied, if necessary, after each layer has been deposited.

The depth of excavation or height of embankment, or the general levelling of the ground, is determined beforehand by fixing gradient or boning pegs at the formation level of the roadway. Previous to commencing the construction of the foundation, whether of concrete or any other material, gradient and contour pegs of wood or iron, generally the latter, are fixed at regular distances apart of from 5 to 8 feet between the kerbs or channels on either side of the roadway. These pegs are fixed so that the top of each represents the finished surface of the carriageway, while a distinctive mark or a second peg alongside of the others shows the depth of the concrete or other material forming the foundation.

In ground of a retentive nature, or where there is any likelihood of water gaining access to the foundation, a subsoil drain, properly trapped, should be formed and connected to the main drain. These subsoil drains are generally placed under the kerb or channels, the trench being filled up to formation level with small stones.

425. Foundations.—The best foundation for any class of paved roadway

is (1) Portland cement concrete, although many other kinds of material are employed, such as (2) bêton, (3) bituminous concrete, (4) hand-set rubble bottoming, and (5) macadam or gravel and furnace cinders consolidated by steam-rolling.

Portland Cement Concrete Foundations.—For first-class work on thoroughfares bearing a heavy traffic, the best foundation is Portland cement concrete composed of from three to four parts by measure of gravel or stones, generally metalling, and one or more parts of clean sharp sand mixed with one part of cement. When this proportion is adopted, the concrete, laid to a thickness of 6 inches, is considered sufficient; but should a weaker composition be employed, consisting of five parts of stone, two parts of fine gravel or sand mixed with one part of cement, then the thickness must be increased. Where the carriageway is subjected to a less heavy traffic, or the thoroughfare is not so important, 6 inches of concrete mixed in the latter proportions is generally made use of.

The foundation of a paved street takes the weight of the traffic and gives stability to the pavement. Portland cement concrete, if composed of good materials and carefully spread, will practically last for generations.

426. (1) Preparing Portland Cement Concrete.—The material, independent of the proportions adopted, is prepared by being mixed on bankers or boarded platforms of suitable size, sufficient to admit of the concrete being turned over the requisite number of times in one direction, and at the same time allow of three batches being prepared at one time.

The materials should be gauged in boxes of a size necessary to secure the proper proportion of the ingredients, which are then heaped up together and turned over twice in a dry state, once while being watered, and three times wet before being loaded into barrows or cast upon the formation bed. When mixing the ingredients, the water should be added in a careful manner by being applied through a finely perforated rose nozzle, under very moderate pressure and in limited quantities, so as to obtain a thoroughly plastic and incorporated mass. The concrete should be thoroughly consolidated *in situ* with heavy beaters, formed to the proper contour of the street and smoothed over with a flat shovel, so as to present an even surface for the setts to be bedded on. Any irregularities which may appear on the surface after the concrete has been placed in position should be made good with fine material before the concrete proper has set or become hard.

Concrete should be deposited in position immediately after being mixed in a wet state, otherwise it may have become partially set and will be consequently of inferior strength.

The surface of a concrete foundation is, after completion, according to the nature of the weather, sprinkled with water from time to time so as to assist the ultimate hardening of the mass. In hot weather, or during the prevalence of frost, the surface of the concrete should be protected by

being covered with old cement bags. When the former condition of weather prevails, it is usual to saturate the bags with water until the whole mass is thoroughly set.

Portland cement concrete foundations are generally allowed to remain from six to ten days so as to properly set before the laying of the paving is commenced. The exigencies of the traffic, however, occasionally demand that the time occupied in executing the work should be shortened. This necessarily means that the proportion of cement to the other ingredients should be increased, and consequently adds to the cost of the work. The laying of the setts may be commenced the day following, but it is advisable, even when the stronger proportioned concrete is adopted, to allow it three clear days to harden before proceeding to lay the paving.

The Portland cement used for concrete foundations is generally specified to bear a tensile strain of not less than 350 lbs. on the square inch, after having been gauged neat with about 20 per cent. of its own weight of water and allowed to stand one day in air and seven days in water. It should be ground so finely that no more than 15 per cent. residue is left on a sieve of 5800 meshes per square inch. The storing of cement is of great importance, and it is usual for the engineer or surveyor to procure a sample of each consignment for the purpose of testing it before it is used.

427. (2) **Béton.**—This description of foundation is also used for pitched pavements. It has been adopted in Liverpool, and is thus described by Mr. H. Percy Boulnois, formerly the City Engineer there * :—

"The ground having been prepared in the usual way, and the channel and kerb stones fixed in position, a stratum of stones (which should by preference be of a non-absorbent character), broken so as to pass all ways through a 3-inch ring, is spread evenly over the surface of the ground, and upon this is placed a layer of cement mortar mixed in the proportions of one of Portland cement to six of fine, sharp, clean gravel, in the method to be described hereafter. Upon this layer of mortar is placed another layer of broken stone—the whole of the stones in each layer to be thoroughly watered while the work is proceeding—and this stone is forced into the interstices of the first layer by the use of flat beaters of wrought iron weighing 16 lbs. each, shaped like square shovels with handles at an angle of 33°.

"This process is repeated until the proper level and contour is reached, and the surface is finished off parallel to the exact curvature of the carriageway. The foundation thus prepared is left until the concrete is sufficiently set or hardened to receive the pavement, which, if possible, should not be less than ten days, although this period may be shortened, when the exigencies of the traffic render it imperative, by strengthening the proportion of cement to the gravel, care to be taken in all cases to periodically water

* *Carriageways and Footways*, by H. Percy Boulnois, C.E.

the surface of the concrete to assist the ultimate hardening, and in very hot weather it is advisable to cover the surface of the concrete with old cement bags thoroughly saturated with water.

"The proportions of broken stone, gravel, and cement used in such a concrete are as follows:—

"Before mixing—Broken stone, eight parts; gravel, six parts; cement, one part.

"After mixing—Broken stones and gravel, mixed together, eleven parts; cement, one part; three parts of gravel having been expended in filling the interstices of the stones."

428. (3) **Bituminous Concrete.**—Another description of foundation extensively used as a substitute for cement concrete is that known as bituminous concrete. It is carried out, after the usual levelling of the ground has been completed and steam-rolled, by spreading a coat of metalling 6 to 9 inches thick, and consolidating it in a dry state by ramming or by rolling. The metalling should be composed of clean broken stone of a size to pass a 2½-inch or 3-inch gauge, and be in a thoroughly dry state. A boiling mixture of pitch, tar, and creosote oil is then poured or floated over the entire surface until all the interstices are filled, and over that a thin layer of small stones or chippings is spread and then thoroughly rolled when the mixture is in a semi-liquid state, so as to effectively incorporate and consolidate the whole mass into a smooth and uniform surface. The bituminous mixture for this class of foundation is generally applied in the proportions of three of pitch to one of tar, or three and one-half of pitch to one-half of creosote oil. As, however, the constitution of the ingredients varies to a considerable extent, the proportions must necessarily be modified accordingly. A cement concrete foundation is undoubtedly superior to that made with a bituminous mixture, but the latter, although more expensive, possesses the great advantage that it admits of the surface being used for laying the paving immediately after it is finished. This class of foundation, therefore, is used in busy thoroughfares where the stoppage of traffic for a considerable length of time would cause great annoyance and obstruction to business.

429. (4) **Hand-set Rubble Foundations.**—This method of forming a foundation for paved carriageways is similar to that employed in connection with macadamized roadways and generally known as Telford's system. The hand-set foundation, or bottoming, consists of a layer of single rubble stones of a uniform depth, varying from 8 to 10 inches, set by hand to form a close, firm pavement. The stones should be laid with their broadest sides downwards in parallel lines across the street, breaking joint as much as practicable. The width of the upper part of the stones ought not to be more than 6 inches nor less than 4 inches, while they should not exceed 12 inches in length. After having been set closely together, the stones should be firmly

wedged up by inserting an iron bar in all possible places, and fixing between the stones thus parted other pieces as nearly as possible of the same depth as the pavement or foundation, until the whole is firmly bound in position. Any projections formed by the pinning pieces above the regular pavement should be broken off, care being exercised, however, not to disturb or loosen the hand-set pitching. It is advisable not to carry on the wedging operations within a distance of 20 feet from the face of the work being laid. The small interstices should be filled with granite or whinstone chippings, or with pea gravel ½ inch to 1 inch gauge, watered and steam-rolled until a perfectly even contour and smooth surface is obtained. Any surplus binding material should be swept off, so as to leave a clean hard surface on which the paving is to be laid.

430. (5) **Macadam, Gravel, and Cinder Foundations.**—Many old macadamized roads which have a sufficient thickness of metalling are at times utilized, where the level of the surface permits, as a foundation for laying a pitched pavement upon. Traffic-consolidated roads are not to be depended on, and are invariably lifted and the material screened either to be made into concrete or to be re-applied and consolidated by rolling, the large percentage of small or useless material and detritus being thus got rid of.

The method generally adopted, however, is to spread a coat of 3-inch gauge metalling so as to give a thickness of 6 inches when consolidated, the manner of accomplishing which is fully described in Part I. of this treatise, Chapters VII. and VIII. This makes a very efficient and cheap substitute for concrete, and so long as the subsoil is kept free from water and the surface drainage properly attended to, good results may be looked for in adopting this class of foundation. Coarse gravel of a sufficient thickness, to which is added at times a small quantity of chalk, makes a very good bottoming, and is principally used where such material can be obtained locally. It seldom occurs that a town is situated where the subsoil is composed of this material. Norwich, however, is an exception, the strata being made up of gravel and chalk, which forms a rough natural concrete on which, with the usual bed of sand, the paving is laid, dispensing with the usual foundation of artificial concrete. The natural surface or bed of many streets in some parts of Norwich, to prevent local yielding, is treated by making or converting the foundation into concrete by flushing the gravel with Portland cement grout.

Furnace cinders, or clinkers, are extensively used in some of the manufacturing towns in England as a foundation for pitched pavements; this class of material, which at one time was much used in Scotland, is now rarely employed as a foundation for street paving. The results obtained are said to be fairly good, and of course the first cost is reduced to a minimum.

431. Paving Setts and laying a Pitched Pavement.—Previous to describing the method of laying and jointing a pitched pavement, it may be advisable to give the following particulars in regard to the different sizes of stone used in making this class of street covering, embracing setts, cubes, and blocks, and the area which one ton weight of each class will cover in square yards. It must be remembered, however, that the specific gravity of the stone employed may vary considerably, consequently the area covered as stated is a broad average.

TABLE XLII.

*Showing size of different stones adopted for pitched pavements with the superficial area which one ton will cover.**

Stone.	Depth.	Width.	Length.	Area in square yards which one ton will pave.
Setts,	5 in.	× 3 in.	× 5 in. to 7 in.	4·5
,,	5½ ,,	× 3½ ,,	× ,,	4·3
,,	6½ ,,	× 3½ ,,	× ,,	3·6
,,	7½ ,,	× 3½ ,,	× ,,	3·1
Cubes,	3½ ,,	× 3½ ,,	× 3½ in.	6·7
,,	3½ ,,	× 3½ ,,	× 3½ ,,	6·2
,,	3¾ ,,	× 3¾ ,,	× 3¾ ,,	5·8
,,	4 ,,	× 4 ,,	× 4 ,,	5·4
Blocks,	4 ,,	× 4 ,,	× 6 ,,	3·6
,,	4 ,,	× 8 ,,	× 8 ,,	5·4
,,	5 ,,	× 3 ,,	× 3 ,,	4·4
,,	6 ,,	× 3 ,,	× 3 ,,	3·7
,,	6½ ,,	× 3½ ,,	× 3½ ,,	3·25

Cubes and blocks are extensively used for crossings, and on streets where there is a considerable gradient the greater number of joints, compared with ordinary paving, gives, under most circumstances, a better foothold for horses, the hoof having but a little way to slip before being arrested by a joint. On the foundation prepared, a layer or cushion bed of fine gravel or clean sharp sand, one-half to one inch thick, is spread, upon which the paving-stones are laid. This provides, so to speak, an elastic bed, and conveys the pressure equally to the foundation supporting the pavement.

The stones should be carefully gauged and coursed, laid in perfectly straight lines at right angles to the centre line of the roadway, and set hard with proper bond, every stone breaking joint with contiguous ones. The surface of the setts is generally laid ¼ inch to ½ inch above the finished level, and any four courses taken together should not measure more

* *The Municipal and Sanitary Engineer's Handbook*, by H. Percy Boulnois, C.E.

than 14 inches for 3-inch setts, and 16 inches for 3½-inch setts, from centre to centre of the joints. The stones to be used should be sound quarried granite, syenite, whinstone, or other approved material of uniform colour, and procured from quarries producing stone of equal quality and durability. When, as sometimes happens, stones from two or more quarries are introduced to expedite the execution of the work, these should be kept separate when laid. All stones should be brought to a regular rectangular shape with a reel head and dressed to the dimensions specified.

Paving setts are sometimes laid diagonally to the line of street, or, as it is termed, in 'herring-bone' fashion; this arrangement admits of the stones wearing in a more regular manner, but the foothold is not so good, and it is more expensive to lay.

432. The jointing of a pitched pavement demands special attention, as by its proper performance will the stability and life of the paving to a great extent depend; and it is now generally admitted that filling the joints with asphalte composition is superior to any other method of effecting this. The grouting of the joints with such a mixture not only makes them impervious, but greatly diminishes the noise inseparable from this class of pavement. To ensure good results bituminous grout must be applied in suitable weather only, as cold and wet are detrimental to its proper execution. The success of pitch grouting depends greatly on the efficiency of the person in charge of the apparatus for mixing and boiling the composition. Should it be too hard, the composition will pulverize in cold weather, while if too soft it will run and become sticky in hot weather. The object to be attained in asphaltic grouting is to make the paving impervious to moisture and to create a bond between the setts with a degree of elasticity sufficient to prevent it from cracking. Pitch grout, when properly manipulated and applied, possesses the quality of becoming sufficiently hard in a few hours after making the joints, so that traffic on the pavement can be admitted shortly after completion.

The method of effecting this kind of joint is performed by filling the space between the setts with clean dry shingle or chippings, small enough to pass through a ⅝-inch riddle, but not so small as to pass through ¼-inch mesh, and entirely free from dust or foreign matter. When the joints are thus filled, either by the material being brushed or scraped into them, the setts should be carefully beaten down to a solid bearing having a uniform surface, and the joints again filled, the shingle or chippings being so regulated as not to reach a greater height than one inch from the surface. The last application of shingle or chippings must be perfectly clean, for which purpose the screening should be performed in water, after which the material is dried in a kiln or by some other suitable means until thoroughly free from moisture. After being worked into the joints, and previous to applying the bituminous grout, care should be taken to keep the chippings or shingle perfectly dry, for

which purpose the paving should be covered with tarpaulins when necessary. The pavement being now ready for grouting, the joints are filled flush up to the surface with the asphaltic mixture applied in a boiling state; and this is best done with a lipped can, care being taken to avoid leaving any of the composition on the top of the setts. Grouting the joints should not be done within at least six feet of the paviors. The whole surface of the pavement is then covered with a thin coating of sharp sand, which completes the operation.

The composition of bituminous grout for paving purposes varies in different parts of the country according to the constitution of the ingredients and the climatic conditions. In ordinary circumstances, the composition may be made in the following proportions, namely, one part pitch to one part of tar, or three of pitch to one of creosote oil. Care and judgment must be exercised, however, so that the mixture will be of such a consistency as to set hard in a few hours after being used, and yet not be brittle. Should any delay occur in the application of the mixture when sufficiently boiled, the proper proportions and consistency must be maintained by adding extra tar from time to time.

433. Cement Grout.—The operations in applying cement grout are similar to those described in the preceding paragraphs. The joints are first filled with chippings or shingle worked in by means of a cramming-iron, then the whole surface of the paving is covered with grout, made of Portland cement, or lime and sand in the proportion of one part of cement or lime to one or 1½ parts of sand, and brushed into the joints with a stumpy broom.

The joints of a pitched pavement grouted with cement or lime mortar require a considerable time to set and properly adhere to the setts (generally from five to six days), as the slightest disturbance caused by vibration or the passage of vehicles over it when the grout is in a green state will seriously affect its efficiency as an impervious pavement. Any yielding of the foundation or subsoil, and at times the effect experienced of heavy individual loads passing over the pavement, will tend to disintegrate the material forming the joint and admit of surface water finding its way to the under bed of the pitching, which will adversely affect the durability of the pavement. Filling the joints with cement or lime grout can be carried out at any time except during the prevalence of frost.

434. Forming the Joints with Sand.—When the foundation is composed of metalling, gravel or furnace cinders, consolidated by steam-rolling, the joint-filling generally consists of rough sand or very fine gravel. The sand is usually washed and scraped into the joints, the paving being carefully beaten down to a firm unyielding bed and uniform surface, and the joints again filled flush. The sand should be washed into the joints by means of a small rose nozzle, and be scraped or crammed in with a thin iron tool. As

this kind of joint-filling material is pervious, it should be adopted only in streets where the traffic is light, as water percolating to the under-bed will, sooner or later, injuriously affect the foundation.

435. Advantages.—Unquestionably a roadway paved with granite or syenite, properly laid upon a hard concrete foundation, forms the cheapest pavement in ultimate cost of any, and in a less degree with setts produced from basalt or whinstone, especially where the traffic is heavy. In many respects this form of street covering answers nearly all the requirements of traffic, and its chief advantages, in addition to durability as a paving material, are that it is adaptable to almost any gradient, and that it gives a good foothold to horses. It is also comparatively hygienic, yields but little dust or mud, and is fairly easily cleansed.

The life of a granite sett pavement varies with the amount and character of the traffic, but from fifteen to twenty-five years may be taken as the time that will elapse before it is necessary to renew the pavement. During this period, however, the setts will require to be lifted, and the wearing surface re-dressed and again laid.

436. Objections.—The objections to this pavement are not numerous, but they are far-reaching and important. The surface of a pitched pavement after being in use for some time becomes, under certain atmospheric conditions, very greasy and slippery. It is a paving which is detrimental to horses, and at the same time one which deteriorates and reduces the life of all rolling stock that passes over it. The incessant noise from the wheel traffic and the iron shoes of horses striking upon it is such that thoroughfares so paved cause great annoyance, amounting in many instances to an intoler-

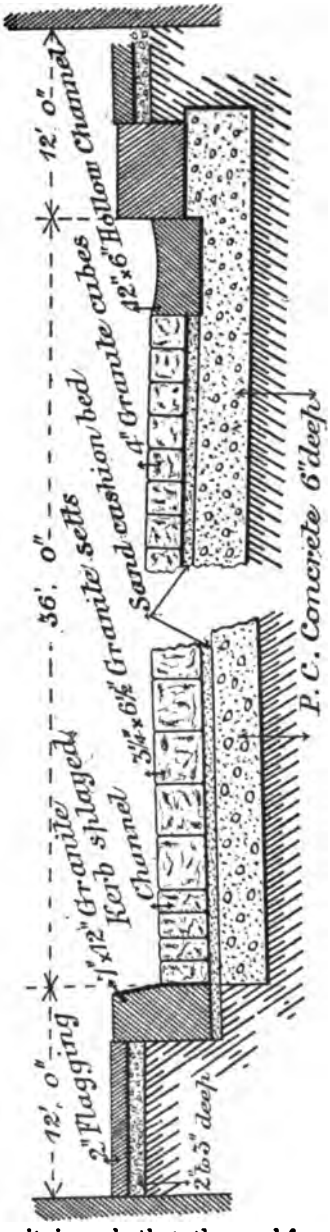


FIG. 124.—Cross-section of pitched pavement.

able nuisance, to business people and tradesmen whose premises adjoin or abut on the street. This clearly points to the necessity, so far as noise is concerned, of employing some other kind of paving for carriageways in good residential quarters or where business premises and shops exist. For streets passing through manufacturing districts, the undoubted advantages of a pitched pavement greatly outweigh the defects mentioned. Fig. 124 shows a cross-section of a first-class pitched pavement.

437. Quality of Setts and Source of Supply.—Local circumstances often determine the kind of stone to be made use of as a paving material; consequently the cost of forming a pitched pavement will vary according to these circumstances and the distance from the source of supply. Great care and judgment are necessary in selecting a stone for paving setts for any particular locality, and regard must be had to the class of traffic to be accommodated and the climatic conditions, especially when the material is obtained from any new source of supply. The igneous and metamorphic rocks of a hard description, and containing a high percentage of augite or hornblende and orthoclase felspar, are those principally employed, although many other kinds of stone are used.

These generally comprise granite, syenite, basalt, whinstone, while paving setts are sometimes made from millstone grit and other sedimentary rocks which are used in places where the traffic is light. Many of the hardest and most durable stones have been discontinued in London and Liverpool owing to the surface of these wearing smooth and becoming slippery, even under normal conditions of traffic and weather. This is notably the case with the old blue Penmaenmawr stone, which, however, is not now much used for setts, but is principally manufactured into kerbs and channels. On the other hand, Aberdeen granite setts are preferred in London to Mount Sorrel and Guernsey granite, although the latter is more durable, because the surface remains rough even after considerable wear. It is also much less expensive to cleanse than Guernsey and the other kinds of granite used for paving. Whinstone setts are greatly used in provincial towns where the traffic is not excessive, and a pavement made with this material, although it wears much faster than granite, invariably maintains a rough surface, and, consequently, does not become slippery like the granite already mentioned.

The principal sources of supply for granite and whinstone paving setts are as follows :—

TABLE XLIII.

Name of Quarry and kind of Stone.	Locality.
England and Wales—	
Mount Sorrel, granite,	Leicestershire
Stoney Stanton, ,,	,,
Enderby, ,,	,,
Bardon Hill, ,,	,,
Charnwood, ,,	,,
Penmaenmawr, ,, (quartz diabase),	Carnarvonshire
Pwllheli, ,, (ophitic diabase),	,,
Clee Hill, ,, (basalt),	Shropshire
Shap, ,,	Westmorland
Whinsill Dyke, whinstone (diabase),	Durham
Cleveland Dyke, ,, (augite, andesite),	Yorkshire
Scotland—	
Aberdeen and District, (granite),	Aberdeenshire
Bonawe, Loch Etive, ,,	Argyllshire
Crarae and Furness, Loch Fyne, ,,	,,
Dalbeattie, ,,	Kirkcudbrightshire
Creetown, ,,	,,
Kilsyth, ,,	Stirlingshire
Most of the counties in Scotland produce whinstone setts, those from which the greater quantity is supplied being Lanark, Fife, Midlothian, Ayr, and Dumbarton.	
Ireland—	
Newry, (granite),	Co. Down
Castlewellan, ,,	,,
Arklow, . ,,	Co. Wicklow
Channel Islands—	
St Samson, Vale Castle, (granite),	Guernsey
Herm, ,,	,,
Ronez, ,,	Jersey
La Moye, ,,	Alderney

438. Besides these sources, capable as they are of furnishing all the material required in this country for the making and repairing of carriageways, a great quantity of setts, kerbs and channels is annually imported from Belgium, Norway, France, Rotterdam, and the quarries on the Rhine (thirty-two in number) worked by the London Basalt Stone Company.

439. Cost of Pitched Pavements — Earthworks. — The excavation, filling, and levelling depend entirely on circumstances, and no definite price per cubic yard can be stated for this class of work.

Foundations.—As already mentioned, the cost of providing a pitched pavement on a concrete foundation varies according to the locality where the work is carried out and the source from which the materials are obtained. The cost of Portland cement concrete does not vary so much when suitable material can be had within reasonable distance; it may be taken to be from

1s. 6d. to 2s. per square yard, 6 inches deep, when the metalling or gravel can be procured for 4s. per ton. When this material has to be brought a considerable distance the price may be as much as 9s. to 10s. per ton; then the cost for a similar thickness of concrete will amount to about 2s. 6d. or 3s. per square yard.

440. Bituminous concrete, for similar reasons, varies in price from 2s. 4d. to 3s. 3d. per square yard laid to a depth of six inches. The cost of forming a foundation of pitched rubble or of metalling will be found in Chapter VIII., Part I.

441. Paving Setts.—The price per ton of paving setts delivered in any particular town depends on the measurements to which they are dressed and the distance from the source of supply. The price per ton for the different sizes used in the construction of carriageways is given for the following cities :—

TABLE XLIV.

Source of Supply.	Setts 6 in. × 3 in. to 3½ in.	Blocks 5 in. × 6 in.	Cubes 4 in. × 4 in. × 4 in.
	s. d.	s. d.	s. d.
City of London—			
Aberdeen granite, . . .	36 0	30 0	36 0
Guernsey granite, . . .	30 0	26 0	30 0
Mount Sorrel granite, . . .	31 0	29 0	30 0
Enderby, ...	31 0	27 0	27 0
Glasgow—			
Crarae, Furness, or Bonawe (granite),	22s. to 28s.	26 0	25 0
Edinburgh—			
Kemnay, Aberdeen (granite), .	28 0	...	...
Ratho and Ravelrig, Midlothian (whinstone),	14 0	...	...
Dundee—			
Aberdeen granite, . . .	16 0	...	...
Pitroddie, Devonshaw, and St Margaret's (Inverkeithing) (whinstone), ...	12 0	8 0	16 6
Aberdeen—			
Rubislaw, Cairney, Cove, Kemnay, Dancing Cairns, Dyce, Corrennie, and Hill of Fare (granite), .	8 6	6 2	7 6

The price per square yard for the paving material will therefore be, at present prices, for setts in London 10s., and in Aberdeen 2s. 5d. per square yard, and for cubes, 6s. 8d. and 1s. 5d. per square yard respectively.

The cost per square yard of a sett pavement, including a concrete

foundation, laying and jointing, will of course vary according to the price of the stones per ton and the wages paid in different cities and towns. The joint filling averages about 1s. 2d. to 1s. 4d. for grouting with Portland cement mortar, and 1s. 6d. to 1s. 8d. for bituminous grout.

442. The amount expended in the annual maintenance of paved streets depends on the volume of traffic which the pavement has to sustain, and other circumstances. It is necessary, in arriving at the ultimate or comparative cost, to give statistics of first cost and outlays for actual repairs executed from time to time, and the cost of lifting and relaying of the pavement, owing to the surface becoming irregular or depressions being formed, once or twice during the actual or calculated lifetime of the pavement.

443. The amount expended annually per square yard in cleansing the surface, a very variable item with the different kinds of granite employed, should also be included, while the sanding of the surface, especially on gradients, to afford better foothold under unfavourable conditions of weather, should, in addition, be embraced under this item.

The cost of cleansing the surface of a street paved with Guernsey granite amounts to 2½d. per square yard annually more than that in the case of a thoroughfare paved with Aberdeen granite setts. On some of the streets situated on a gradient in the city of London, the cost of sanding is stated to amount to about £6 per mile annually.

Aberdeen granite paving, although it wears under heavy traffic to a greater extent than Guernsey, is, nevertheless, eminently suitable for carriageways where a good and safe foothold is of primary importance, and particularly for steep gradients.

Paving setts which have been exposed to heavy and continuous wheel traffic for a number of years, when taken up are found in most instances to require a certain amount of re-dressing. This is caused by the wear of the top of the setts, the amount of which will vary according to the nature of the stone, the manner in which the pavement has been laid, their position in any particular thoroughfare, and the character of the traffic. Setts which have been paved with wide joints are found to be considerably worn or rounded on the arrises, to the extent of 1½ inch in some cases, which entails a large waste of material in re-dressing them to a rectangular form.

444. The following Table XLV. gives the first cost, description of foundation and class of setts used, annual repairs, cleansing, and the lifetime of carriageways paved with setts, so far as can be obtained, in the chief cities and towns of the kingdom. The order is that of the population of the towns mentioned.

TABLE

NAME OF TOWN.	First cost of sett paving per square yard.	Description of foundation and size of setts in inches.
1. London—Hammersmith,	16s. including foundation.	P. c. concrete 6 in. deep, 5×7.
,, Holborn,	14s. 6d.	,, 6 ,, 3×7, A.
,, Lambeth,	13s. 7½d. on existing foundations.	,, 12 ,, 4×7, A.
,, Mile End (Old Town),	13s. 6d. ,, ,,	,, 6 ,, 3½×7.
,, Shoreditch,	17s. including foundation.	,, 6 ,, 3×7, A., G.
,, Stoke Newington,	16s. 6d. ,,	,, 6 ,, 4×7.
,, Strand,	14s. 9d. on existing foundation.	,, 6 ,, 3×9, A.
,, St Martin's-in-the-Field, Charing Cross,	15s. ,,	,, 6 ,, 3×7, A., E., G.
,, St Mary, Islington,	12s. 6d. to 13s. 6d. on existing foundation.	,, and blue lias lime 6 to 9 in., 3×6, A.
,, St Pancras,	14s. 6d.	P. c. concrete 6 to 9 in., 3×6, G.
,, Whitechapel,*	14s. 7d.	P. c. concrete 6 in., 3×7, 3×9, A., G.
2. Glasgow,	Granite—13s. 6d. to 14s. 9d. including foundation. Whinstone—10s. 8d. to 11s. 4d. including foundation.	P. c. concrete 4 to 6 in. deep 3½×6 to 7, B., F. .. .. ..
3. Liverpool,	11s. to 13s.	P. c. concrete 6 in. deep, 4 in. cubes, and 3½×6½×5×7.
4. Manchester,	10s. 6d. including foundation.	Furnace cinders and pinned foundation, 3 to 3½×6.
5. Birmingham,	12s. ,, ,,	P. c. concrete 6 in. deep, 3×6.
6. Sheffield,	13s. 6d. ,, ,,	P. c. concrete 6 to 9 in., 3×5×6, and 4 in. cubes, A., D., M., P., I., W.
7. Belfast,	15s. to 20s. including foundation and re-setting kerbs, etc.	P. c. concrete 9 in. deep, 4×6.
8. Bristol,	14s. including foundation.	P. c. concrete 6 in. deep, 3×5, N., W.
9. Edinburgh,	10s. 6d. on existing foundations.	,, 6 ,, 3×4×7, A.
10. West Ham,	15s. 6d. including foundation.	,, 6 ,, 3×6 and 4×7, A., G.
11. Dublin,	14s.	P. c. concrete 6 in. deep, 3½×6, W.
12. Bradford,	12s. 6d. ,, ,,	,, 6 ,, 3×6, M., D., T., W.
13. Newcastle-on-Tyne,	11s.	P. c. concrete 6 in. deep, 3×6.
14. Leicester,	8s. 6d.	,, 6 ,, 3×5.
15. Bolton,	10s. 6d.	,, 6 ,, 3×6.
16. Dundee,	10s. 6d. to 13s. 6d. including foundation.	,, 6 ,, 4×3½×6, A., ,, Pitroddie, I.
17. Aberdeen,	11s. 9d. to 12s. 6d. ,, ,,	P. c. concrete 6 in. deep, 4 in. cubes and 3½×6, A.
18. Birkenhead,	.. .. ..	,, 6 ,, various, P.
19. Wolverhampton,	11s. 3d. including foundation and excavation.	,, 6 ,, 4 in. cubes, and 3×7 on gradients exceeding 1 in 30.
20. Coventry,	12s. 6d. including foundation.	P. c. concrete 6 in. deep.
21. Bury,	12s. ,, ,,	,, 6 ,, 3×5, P.
22. Hanley,	10s.	,, 6 ,, 3×5×6, all sorts.

REFERENCE

A. Aberdeen. B. Bonawe. D. Dalbeattie. Ds. Devonshaw. E. Enderby. F. Furness. G. Guernsey.

* This Table is compiled from various sources, but principally from an article on 'Paving of Carriageways,'

XLV.*

Description of grouting.	Annual cost of maintenance per square yard: (a), repairs; (b), cleansing and watering.		Estimated life of sett paving under heavy traffic.	REMARKS.
	a.	b.		
Lime.	.. ..	.. ..	25 years.	.. .. ..
P. cement.	.. ..	.. ..	.. ..	.. .. ..
,,	.. ..	.. ..	19 years.	Very heavy traffic.
Lias lime.	Practically nothing for first 20 years.	.. ..	25 ,,	.. .. ..
P. cement.	.. ..		20 ,,	.. .. ..
,,	1d. average for 8 years.	2½d.	15 to 20 years.	.. .. ..
,,	.. ..	.. ..	.. ..	Setts were worn 5 to 6 inches when lifted after 10 years' service.
,,	.. ..	.. ..	15 to 20 years.	Being replaced by wood.
P. cement and blue lias, bituminous.	.. ..	.. ..	.. ..	.. .. ..
P. cement and pitch.	.. ..	.. ..	20 to 30 years.	Renewal or re-dressing necessary to remove slipperiness.
,, (1 to 3).	.. ..	4½d.	9 years.	.. .. ..
,, and bituminous.	.. ..	.. ..	25 ,,	Other 25 years after re-dressing and relaying.
Bituminous.	.. ..	.. ..	30 ,,	.. .. ..
,, stone and chippings.	½d.	.. ..	15 to 30 years.	.. .. ..
P. cement.	1d.	4d.	25 ,,	.. .. ..
Pitch and tar.	.. ..	.. ..	20 to 25 ,,	.. .. ..
P. cement and gravel.	*Nil* for first 10 years; 1d. afterwards.	.. ..	20 ,,	Other 20 years after re-dressing and relaying.
,, and bitumen combined.	About 5d. combined.	.. ..	18 ,,	Stones require to be re-dressed after this period of service.
,, and asphalt.	3d.	.. ..	30 ,,	.. .. ..
P. cement.	.. ..	.. ..	.. ..	.. .. ..
Bituminous.	1d.	10d. to 1s.	30 years.	Paved with good granite.
,,	.. ..	.. ..	20 ,,	.. .. ..
,,	.. ..	.. ..	24 ,,	Granite and whinstone.
,,	5½d. during life, including first cost.	1½d.	25 ,,	.. .. ..
Broken stone with ballast or gravel.	2d.	.. ..	30 ,,	.. .. ..
P. cement and bitumen.	3d.	.. ..	18 to 30 years.	Whinstone and granite.
,, ,, and chips.	.. ..	.. ..	Depends on nature of traffic.	Streets have lasted over 40 years where undisturbed.
Bituminous.	.. ..	.. ..	.. ..	.. .. ..
Pitch and broken stone.	.. ..	.. ..	.. ..	Only been recently laid.
Pitch.	.. ..	8½d.	.. ..	Ditto.
P. cement and pitch.	.. ..	.. ..	40 to 50 years.	.. .. ..
Bitumen finished with cement.	.. ..	.. ..	30 years.	.. .. ..

TABLE.

I. Inverkeithing. M. Mount Sorrel. N. Newry. P. Penmaenmawr. T. Threlkeld. W. Welsh.

by Mr H. Richardson, which appeared in *The Surveyor and Municipal and County Engineer*, 24th March 1899.

445. From the foregoing table it would appear that the average lifetime of a granite sett pavement in the City of London is 18½ years, the longest being 25 years, while the shortest is in the Whitechapel district, where the life of this description of paving is stated to be only nine years. In the former two cases the pavement is taken up and relaid once during the lifetime mentioned.

The ultimate annual total cost for laying and repairs (taken on an average of the different districts in the metropolis, but exclusive of excavation, foundations, sinking fund and interest) may be stated as follows:—

TABLE XLVI.

	Pence.
First cost 14s. 6d. per square yard, lifetime 18½ years, . .	9·40
Cost of repairs, ...	1·50
Lifting, re-dressing setts, and relaying, 1s. per square yard, .	0·54
Cleansing the surface, ...	3·00
	14·54

or, say, 1s. 2½d. per square yard annually for maintaining the covering of the street in good repair, but if the price of the foundation is included, and the probable life be 50 years or more, the cost would be 1s. 3¼d.

In large cities and provincial towns where the traffic varies from heavy to medium and light vehicular conveyances, the lifetime may be stated at from 25 to 40 years, while the annual cost as detailed above will average about 1s., 10d., and 6d. respectively, the first cost of the paving, exclusive of foundations, averaging from 12s. 6d. to 7s. 6d. per square yard.

These figures clearly show that pitched pavements constructed alike as regards foundations and kind of material used for making the setts is simply a question of traffic. Although statistics of traffic are not available for all the towns referred to, still the inference points to that conclusion.

CHAPTER X.

WOOD PAVEMENTS.

446. Carriageway pavements constructed of wood were introduced into London and laid on Stead's system in front of the Old Bailey in 1839. It is stated, however, that wooden blocks were used in Russia for some hundred years previous to that date, while in America wooden street pavements were tried experimentally in New York during 1835–6.

Most of the earlier attempts to construct a pavement with blocks of soft wood resulted in failure, owing to the inferior quality of the material, combined with the careless and improper methods adopted in laying the blocks without a foundation of cement concrete.

From the time when wood pavements were first laid in the metropolis many different forms were patented, but as most of these are now only known by name, few need description here.

Of late years the introduction of Australian hard woods, mostly from trees belonging to the eucalyptus family, and the improvement effected in cutting and laying the blocks, have resulted in this class of pavement being extensively used in many of the cities and provincial towns in the kingdom.

447. Compared with the other pavements of recognized merit, wood is practically noiseless, and it is no doubt owing to its possessing this quality that it has been so extensively employed in recent years. It also gives the minimum of traction of any pavement, asphalte excepted, and affords a good foothold for horses under varying weather conditions when the surface is kept in a thoroughly clean state.

The following are some of the wooden pavements referred to above.

448. Stead's Wood Pavement.—This pavement was laid on a bed of gravel 3 inches thick on ground previously levelled and well beaten, the object of this layer being to drain the surface water percolating through the joints of the pavement. The blocks of wood consisted of Scotch or Norway fir, and were hexagonal in shape, 6 to 8 inches across and from $3\frac{1}{2}$ to 6 inches deep. The upper edges of the blocks were chamfered and grooves were formed across the wearing surface in some cases. In several instances there

was a concrete foundation 3 inches thick, composed of small broken stones flushed with Ardwick lime or Roman cement. Pavements were also constructed by Stead, composed of round blocks of wood placed vertically and laid close together, the interspaces being filled with sifted gravel or sharp sand.

449. De Lisle's Wood Pavement.—This consisted of blocks the upper and under surfaces of which were cut diagonally to the grain, forming parallelopipeds, placed alternately in reversed positions; two holes were cut on each side of the blocks, and dowels or trenails inserted in these locked the blocks together.

450. Carey's Pavement.—This was the first durable wood pavement laid in London, many of the streets having been paved with it in 1841 and subsequent years. It consisted of pine blocks 6½ to 7½ inches wide, 13 to 15 inches long, and from 8 to 9 inches deep laid on a foundation of ballast; the cost of this paving was 14s. 2d. per square yard. The size of the blocks was reduced, in 1866, to 4 inches in width and from 5 to 6 inches in depth, the length being 9 inches. They were formed with double bevelled surfaces, which when laid, came together, the intention being to prevent the blocks shifting and also to distribute the pressure on one block over the contiguous ones. The joints, ⅜ inch in width, were grouted with lime and sand mortar. It is worthy of note that the life of this pavement, taken on an average, extended to nine years on streets having a heavy traffic, and to eleven years on light-trafficked thoroughfares. The total cost of construction and maintenance during the lifetime of this pavement amounted to 2s. 8d. per square yard in the former case and 2s. 5d. per square yard in the latter annually.

451. Improved Wood Pavement.—This pavement, introduced from the United States, was originally laid with blocks, hexagonal in shape, 6 inches across and 8 inches deep. The first piece was laid in London in 1871; but the earlier method of forming this pavement was subsequently considerably modified. After excavating to the profile and section of the street, a layer of sand, fine mortar stuff or dry earth was spread to a depth of 4 inches. On this bed two layers of 1-inch deal boards, previously dipped in boiling tar, were laid close together transversely and longitudinally. The object of this flooring of planks was to form an elastic foundation and to distribute the weight applied on one block over a large surface. This method of forming the foundation was, for obvious reasons, abandoned, and a thin concrete one was substituted; one layer of the 1-inch boards, however, was retained, and was laid on the top of the concrete.

Upon this foundation, blocks, measuring 3 inches wide, 6 inches deep, and 9 inches long, dipped in tar, were laid. The longitudinal joints were made ¼ of an inch wide, and kept apart by a fillet nailed to the flooring board, the heading or end joints being laid close or butting. They were filled to a depth of 2 inches with a mixture of boiling tar and pitch, and

the space above was finished with fine dry ballast rammed into the joints by means of a caulking iron, and flushed with the tar and pitch composition. The work was completed by the whole surface being strewn with small gravel (to which was added boiling tar), and by sand then being thrown over the surface.

The object of sprinkling gravel over the surface was to indurate the wearing surface of the wood; while the elastic binding material, with which the joints were filled, was intended to produce an impervious pavement.

452. Ligno-Mineral Pavement.—This pavement, known as Trenaunay's system, was introduced from France. It appears to have been the first that was provided, as an original part of the system, with a hard concrete foundation moulded to the required curvature of the street. Upon the concrete foundation hard wood blocks of oak, elm, beech, or ash, 3 inches by 6 inches and 9 inches long, chamfered on the upper edges, were laid, the upper and lower surfaces of the blocks being cut at an angle of about 60 degrees to the grain of the wood, with a view to expose the fibre obliquely to the wearing surface, and also to distribute the weight of the traffic from one block to those adjacent in the line of thrust.

A groove cut horizontally along the sides of the blocks near the base was filled with asphaltic mastic; the joints were also partially grouted with the same composition, the remaining space being filled with lime and sand grout. The blocks, previous to being laid, were subjected to a process called 'mineralization' to render them tough and more durable. Besides the hard woods mentioned, fir was used, and was treated in a similar manner to preserve the wood; these blocks, however, were laid in an upright position with vertical fibres. This pavement was laid in various streets in London in the years 1872 and 1875.

453. Asphaltic Wood Pavement.—This system of wood paving, originally patented by Copeland, was constructed in the following manner:—

The ground having been excavated as required, a foundation of blue lias lime concrete, consisting of one part of lime to five or six parts of ballast, was laid to a depth of 6 inches, finished to the proper contour of the road section. Upon this foundation a coat of mastic asphalte was laid from $\frac{1}{2}$ inch to $\frac{3}{4}$ inch in thickness as a cushion for bedding the pavement. The wood blocks, of Baltic fir, 3 inches wide, 6 inches deep, and 9 inches long, were laid in transverse courses with the grain of the wood upwards. Interspaces or joints about $\frac{9}{16}$ inch wide between each line of blocks were regulated by placing strips of wood against each course as they were laid. These were filled to a depth of $1\frac{1}{2}$ inch with melted asphalte, which partially re-melted and united with the coating spread on the foundation. The remainder of the joints was filled with a grout composed of hydraulic lime and sand, whereby the whole pavement was made into a solid mass.

The surface of the paving was finished with a top dressing of sharp sand or fine gravel strewn over it, which, when worked in by the wheel traffic, indurated the surface of the wood blocks.

In the original pavement, holes were pierced at the sides of the blocks and were filled with liquid asphalte in order to afford an additional key to the paving; this arrangement, however, was dispensed with in the later forms of this pavement.

This street covering was first laid in London in 1874, at the east end of Cannon Street. The foundation consisted of Portland cement concrete, 9 inches deep, over which a layer of mastic asphalte, $\frac{3}{4}$ inch thick, was spread. The blocks of soft wood steeped in tar were bedded in this mastic cushion and laid in courses across the street with $\frac{5}{8}$-inch joints. Each block had two holes about $\frac{3}{4}$ inch in diameter, and $\frac{5}{8}$ inch deep bored in each side, and were filled with the liquid asphalte when the joints were being grouted. The upper part of the joints was rammed with screened gravel and filled with asphalte grout, and the pavement, as already mentioned, was covered with fine gravel and sand. The pavement was characterized as impervious to water, and the foundation when examined a considerable time after being laid, was found to be dry and in good condition.

454. Henson's Wood Pavement.—The foundation for this system of wood paving was composed of 6 inches of blue lias lime concrete floated with a 2-inch layer of cement concrete of fine quality. Upon this was placed a layer of ordinary roofing felt previously saturated with a hot asphaltic composition of distilled tar and mineral pitch. This layer was intended to give elasticity to the road covering, which was composed of Swedish yellow deal blocks, 3 inches by 6 inches, and 9 inches long, laid with the grain upwards. The joints were formed with strips of saturated felt, the blocks being driven together so that the space between the courses was reduced to less than $\frac{1}{4}$ inch in width. At intervals of every three or four rows a course of blocks, grooved along the middle, was laid, to aid in giving proper foothold for horses. The surface was finished by spreading a hot bituminous compound, and then a coating of sand.

455. Mowlem & Co.'s Method.—This description of wood pavement is laid on a foundation of concrete varying in thickness according to the nature of the subsoil and the traffic. The blocks of yellow deal, 3 inches by 6 inches or 7 inches deep, are laid direct on the foundation, the joints, varying in width from $\frac{3}{8}$ inch to $\frac{1}{2}$ inch, being filled in with lias lime and sand grouting, the surface of the blocks being afterwards indurated by strewing it with shingle which was run in by the vehicular traffic.

456. Duffy's Patent Wood Pavement.—It is claimed for this patent wood paving that the depth of the blocks can be materially reduced by the introduction of dowels or binding keys inserted into recesses or holes on either side of each block, effectually fastening them together, and distri-

buting the weight of the traffic over a considerable area. By being so bound together, the blocks do not become loose or rise; it is an inexpensive pavement, and is easily laid. This system of paving was laid on the roadway of the Tower Bridge in 1895. It has also been recently laid in front of the Marylebone terminus of the Great Central Railway Company.

Of the other patented systems of wood paving adopted and carried out, many of which are similar to those already described, with probably some slight alterations in detail, the following may be mentioned:—Harrison's, Newton's, Stone's, Gabriel's, Wilson's, Lloyd's, Trosser's, and Elli wood paving.

457. The experience acquired in laying the wood pavements described in the preceding paragraphs clearly points to simplicity of construction. The many patents for elastic foundations, interlocking the blocks, and forming grooves on the surface, have all been found to be extremely complicated and deficient in many important respects.

458. Gradients.—The steepest gradient which could be successfully laid with wood paving was, until recently, considered to be 1 in 40. Streets having steeper gradients are now paved with wood, as for instance Savoy Street and Arundel Street in London, which are situated on gradients of 1 in 12 and 1 in 14 respectively. It is, however, considered in modern practice that streets should not be paved with wood where the gradient exceeds 1 in 27. Under certain atmospheric conditions the paving becomes slippery, and requires sand or fine gravel sprinkled over the surface to ensure a good foothold. The frequency with which this has to be done increases as the gradient becomes steeper, and the expenditure under this head, in giving an artificial foothold, amounts to a considerable sum annually.

459. Contour.—The convexity adopted for a wood pavement is generally $\frac{1}{60}$ to $\frac{1}{80}$ of the width of the carriageway, and may be made in the form of a segment of a circle, or according to the ordinates shown in fig. 121.

Methods of Constructing Wood Pavements.—The methods adopted in laying a wood pavement carriageway and practised at the present time will now be described. The wood may be either soft or hard.

460. Foundations.—Portland cement concrete is invariably adopted for forming the foundation of wood pavements of varying strength and thickness according to the traffic, nature of the subsoil, and position of the street. In other words, the foundations for a pitched and a wood pavement are similar; but in the case of the latter paving, an additional covering of fine concrete or cement rendering is applied on the top of the concrete foundation so as to form a true and even surface on which the blocks are directly laid without the intervention of any cushion layer.

In most cases the old foundation of concrete, which has done service for

other descriptions of paving material, are utilized, with the addition of being floated with cement mortar to render the surface smooth, and make good any depression or alteration of the contour which the finished surface of the street is to assume when completed. This is accomplished by fixing level-pegs longitudinally and transversely to secure efficient surface drainage. The intermediate points are determined by means of boning-rods, and the carriageway is then divided into panels or bays of a certain width for carrying on the operations of floating the surface with cement mortar. It is performed by driving an iron wedge into the concrete foundation at intervals of five or six feet across the roadway between the kerbs or channels. Wood pegs are driven into the holes thus made, and the height of each is fixed by boning; the tops of the pegs are then cut off, where necessary, to the proper level. On the top of these a lath $2\frac{1}{2}$ inches by $\frac{3}{4}$ inch is fixed by nails forming a template, the upper side of which corresponds to the finished surface and the required contour of the cement mortar coating. The panels may vary from 12 to 15 feet in width, and each alternate one is completed and allowed to set before commencing the others. The cement mortar or rendering is regulated by means of a straight edge, worked between the lath-templates transversely, which ensures the surface being finished in a uniform manner. When the whole has become hard, the laths are removed and the spaces filled in with thick cement grout.

As there is no cushion of sand made use of in this paving, at all events in first class work, it is absolutely necessary that the concrete should be thoroughly hard before commencing to lay the paving blocks. The time necessary for this will, to a certain extent, depend on the weather, but is usually from ten to twelve days; in many cases, however, the laying of the blocks may be commenced six days after the completion of the concrete foundation.

461. The practice in recent years has been to lay wood blocks with the fibre vertical, instead of inclined or oblique, as in many of the earlier wood pavements. The wearing capacity of blocks laid with the fibre of the wood vertical is nearly double that of blocks set at an angle of 45 degrees, and four times greater than of those laid in a horizontal position. Wood pavements are generally divided into two classes, namely, soft wood and hard wood.

462. Soft Woods.—For the most part the kind of timber used in this class of paving is yellow deal or Baltic redwood, which has superseded those formerly used in this country, such as larch, oak, and elm, although the latter kinds of timber are still employed to a limited extent.

As soft wood absorbs a considerable amount of moisture, plain blocks should not be used. From a hygienic point of view, this defect has, to a certain extent at least, brought about the substitution of hard for soft woods as a paving material. The failure of soft wood pavements is, on this account,

doubtless traceable to the imperfect manner in which they have been laid with untreated blocks and wide joints. The absorption of moisture is prevented to a great extent by creosoting the timber; much, however, depends on the condition of the wood when treated and the method adopted in preserving it.

The treatment of the blocks lessens their tendency to expand when laid, and minimizes the trouble caused by displacement of kerbs, channels, lamp-posts, and damage to gully gratings and other fixtures, owing to the swelling of the blocks transversely across the street. The wearing qualities of soft woods are considerably enhanced by subjecting the timber to a creosoting or pickling process. The amount of moisture absorbed by yellow deal plain blocks is stated to be about 23½ per cent.

Table XLVII. gives the comparative expansion of six creosoted as against six plain soft wood blocks after immersion in water for forty-eight hours in percentage on the original dimensions.*

TABLE XLVII.

	Creosoted.	Plain.
On length of block, ...	·099	·6
On width ,, ,, ...	·57	·83
On depth ,, ,, ...	·15	·31

"These expansions would represent in a carriageway 30 feet wide, 2½ inches for plain blocks and practically ⅜ inch for creosoted blocks, if they were under the same conditions; but, of course, actually the soaking of the blocks to this extent never occurs, and the expansion, therefore, is sufficiently provided for by a narrow sand joint against the kerb, the space being subsequently grouted up after the blocks have found their position."

To further illustrate the comparative expansion of plain and creosoted soft wood paving blocks, the following particulars may be given. In laying the roadway in Piccadilly, London, with plain soft wood blocks, expansion was provided for to the extent of 3 inches on each side of the thoroughfare next the kerbs. Owing to the swelling of the blocks the whole space originally allowed was taken up, when further provision for expansion had to be made by removing a longitudinal course of blocks, 2 inches in width, from each side of the carriageway. This made the amount of expansion equal to 5 inches at the channel, or a total of 10 inches in the roadway. In Regent Street the paving blocks were treated previous to being laid. A similar allowance for expansion was provided for on either side of the street, but in this case the swelling of the wood paving only amounted to 2 inches on the total width of the thoroughfare.

* *Notes on Wood Paving in Ipswich*, by Edward Buckham, M.I.C.E., Borough Engineer.

463. Creosoting Soft Woods.—The best natural method of preserving timber is to have it well ventilated and seasoned. Decay in wood takes place through many causes, but principally by the absorption of water into the cells of the timber. The wood used for paving purposes should be carefully selected, free from sap, close and even grained, and thoroughly well seasoned. Preserving timber so as to prevent decay is accomplished by the process of creosoting or impregnating the wood with metallic salts, which can be carried out by various methods.

The most successful preservative is creosote oil, a product obtained in distilling tar, which is injected into the timber after it is cut into blocks; and the blocks then placed in a close cylinder after the air and moisture in the wood have been exhausted. For paving blocks of yellow deal a quantity of 10 lbs. to the cubic foot gives satisfactory results.

Table XLVIII. shows the comparative weight of water absorbed by soft woods, for plain or untreated blocks, for those impregnated with creosote oil (10 lbs. to the cubic foot) and for blocks treated with 'Carbolineum Avenarius'* (65 gallons to 1000 3 inch by 5 inch by 9 inch blocks).

TABLE XLVIII.

	Weight before.	Weight after.
Plain blocks, 3 in. × 5 in. × 9 in., . .	16 lbs.	18 lbs.
Creosoted blocks, ,, . . .	20¼ ,,	21 ,,
Carbolized blocks, ,, . . .	18 ,,	19½ ,,

"These statistics prove the wood to be less susceptible to absorption after treatment than before, the advantage being in favour of creosote."

As the strong smell emanating from creosoted wood is objected to in many instances by residents, the introduction of carbolized blocks into certain quarters of cities and towns has been favoured.

The somewhat primitive method of simply dipping the deal blocks into creosote oil previous to laying them does not, for many reasons, appear to be reliable, although very good results are obtained by this method of treating the timber by the Strand District Board of Works, London, which will be further alluded to in a subsequent paragraph. It is admitted that creosoting soft wood blocks, if properly performed, about doubles the life of the timber; there is also a great advantage accruing from its being so treated from a sanitary point of view. The life of a soft wood pavement varies considerably according to the amount of traffic, quality of the wood, and whether the blocks are used plain or have been subjected to treatment, and the method adopted in laying the pavement.

* "Wood Carriageway Pavements," by Mr. Chas. Mason, A.M.I.C.E., *Proc. Incor. Assoc. Municipal and County Engineers*, vol. xx. p. 68, 1893–94.

464. The life of a soft wood paving, estimated by wear in some of the busiest thoroughfares in the Metropolis, averages about seven years, although longer periods of service have been recorded; for instance, in central London this pavement has had a life of from eight to nine years in the Strand between Exeter Hall to St. Mary's Church and Newcastle Street to Temple Bar. Yellow deal blocks taken from this thoroughfare were found, after five years' service, to have been worn to a depth varying from $1\frac{3}{8}$ inch to $2\frac{1}{4}$ inches, the original depth of the blocks having been 6 inches. In another instance a yellow deal block taken from the carriageway of Charing Cross, the original depth being 5 inches, showed it to have been worn or reduced to $1\frac{1}{8}$ inch after five years' wear. In provincial towns where the character and extent of the traffic is from medium to heavy the life of a creosoted soft wood pavement may be taken at from twelve to fifteen years.

The unequal wearing of the wood through latent defects and depressions caused by subsidence of the foundations over trenches where repairs to gas and water mains have been found necessary, quickly converts the paving into an irregular surface, which, if allowed to remain, or if the renewals are not sufficiently frequent, will naturally create an insanitary condition of things, and render the scavenging more difficult.

465. Hard Woods.—The hard woods hitherto principally used in this country for street pavements are Karri and Jarrah from Western Australia, but other kinds are being introduced from New South Wales, such as tallow wood, black butt, blue gum and red gum. White oak and gum wood from South Carolina and Mora wood from Demerara are also being introduced; and as these are of a tough and fibrous nature, and considerably lighter than Jarrah, it is considered they will be less noisy and slippery than the other hard woods mentioned.

With the exception of a small trial piece of hard wood paving laid in Chelsea in March 1888, the first street pavement of Australian hard wood was executed in Westminster Bridge Road, London, in May 1889. This thoroughfare was paved with Jarrah, and is noted for the incessant and exceedingly heavy traffic which passes over it. To give some idea of what this means it may be mentioned here that on the west side of the roadway or leading towards Westminster the daily wheel traffic is reckoned at 1002 tons per yard of width of roadway from 6 a.m. to 6 p.m., during which time 3574 vehicles pass.

Hard wood blocks are generally laid in their natural state, as, owing to their being very dense, creosoting would not materially affect the durability of the timber, and in any case could only penetrate the blocks to a very limited extent. The dipping of these blocks in a bituminous composition, as practised in some districts, is not so much for the purpose of preserving the timber as to form an impervious joint. From a sanitary point of view hard

wood is superior to a soft wood pavement, and when the blocks are laid with a close joint the defects hitherto associated with this class of pavement are almost entirely removed.

The liability to contraction, however, is an objection, and when this takes place the spaces left between the blocks are filled with deleterious matter which cannot be removed. The necessity of providing expansion joints at the kerbs or channels is undoubtedly a serious drawback, but this defect is more likely to be overcome by using only properly seasoned timber in as fresh a condition as possible, and by laying the blocks close together with a bituminous joint.

Many of the difficulties which have arisen are directly attributable to the method of laying the pavement and the condition of the wood when used; it is well known that properly seasoned wood blocks cease after a time to expand or contract. The comparative power of absorbing water of the two Western Australia woods, Jarrah and Karri, is given by Mr. W. N. Blair as follows :—

Jarrah blocks, ...	10·71 per cent.
Karri ,, ...	7·77 ,,

Jarrah weighs, when freshly cut, slightly over 70 lbs. per cubic foot, which is reduced to 65 lbs. and 60 lbs. when thoroughly seasoned. All wood blocks for paving purposes, whether hard or soft, should be carefully selected, free from sap, and close and even-grained. It is generally admitted that wood paving is less noisy and less slippery than any other kind of pavement, with one exception, which will be referred to further on, suitable for heavy traffic. However, it is necessary to cleanse the pavement periodically by washing the surface to remove foreign matter, which is the real source of slipperiness in a pavement and of its unsanitary condition by reason of the emanation of offensive smells. Under certain atmospheric conditions slipperiness is temporarily removed by occasional sanding and sprinkling fine gravel or crushed flint screenings over the surface, especially on gradients, so as to ensure a good and safe foothold for horses. In the Strand district of London, where soft wood pavements predominate, crushed rock salt is used, especially during the winter months, to assist in cleansing the surface when being washed.

466. Laying Wood Blocks and Jointing.—The dimensions of the blocks used in wood paving are generally 3 inches to 4 inches by 5 inches to 6 inches by 9 inches. They should be cut square to the exact size by machinery, so as to ensure uniformity when laid as a pavement. In carrying out the work the blocks are laid transversely across the street with the fibre of the wood vertical. They are placed directly on the concrete foundation, which is the practice in first-class work, or on a cushion of sand of from $\frac{1}{2}$ inch to $\frac{3}{4}$ inch deep.

The latter system is adopted with a view to reversing the blocks when they have become rough or uneven through wear, and thus making the surface smooth again. This arrangement, by which the life of the pavement is prolonged, can only be advantageously adopted in streets which have moderate traffic. The making of the joint is performed in various ways, the material used being either cement grout or a bituminous composition. The wide joint which was characteristic of this class of pavement some years ago has, in most recent work of this description, been practically eliminated. It is generally admitted that wide joints on a level or comparatively level carriageway do not afford any better foothold for horses than paving laid with close joints. On gradients, however, it is usual to set the blocks with a $\frac{1}{4}$-inch or $\frac{3}{8}$-inch joint for the safety of horse traffic.

467. Joints.—When the joints are to be grouted with Portland cement or bituminous grout a certain space between the blocks is imperative. A joint $\frac{1}{8}$ inch to $\frac{3}{8}$ inch, according to the conditions, is required, for which provision is made by inserting a lath of the necessary width and about one inch deep laid on edge at the bottom of the joint and left there. These wooden strips or laths, besides providing for the necessary width of joint, maintain the regularity of the joints, and they are in some instances placed at the top of the blocks and removed when the joints are filled. The cross joints are likewise left open, but without the lath.

The bituminous grout, composed of pitch and creosote oil in the proportion of 1 cwt. of pitch to $1\frac{1}{2}$ to 2 gallons of oil, according to the quality of the pitch, is then poured over the pavement by means of a bucket, the joints being filled by brushing the fluid into them or by using a rubber squeegee which pushes the liquid over the surface, fills the joints and leaves as little of the grouting mixture on the surface of the carriageway as possible.

468. A composite joint is also made use of, and is formed by pouring the bituminous composition into the joints so as to fill the lower portion of them to a depth of 2 inches; the remaining or upper portions of the joints are then grouted with Portland cement mortar composed of one of cement to three of clean sharp sand.

Many of the soft wood pavements in London are now laid with a close joint, to ensure which sledge-hammers are used to drive the paving blocks together at every twelfth or fifteenth course. The surface is then flushed over with hot tar, which penetrates between the blocks and makes a waterproof joint.

469. The method now generally adopted in laying hard wood pavements is to dip the blocks on one side and end in a hot pitch composition when being laid, and placing them together without any appreciable joint, thus making a thoroughly efficient and impervious pavement. The surface of the carriageway covering is at times flushed over with the bituminous

mixture so as to make the joints thoroughly secure and at the same time to prevent any tendency of the wood blocks to absorb surface water, and thereby minimise expansion. A bituminous joint costs about 7d. per square yard of paving laid.

470. In Sydney, New South Wales, where wood pavements, formed of different kinds of timber, have been in existence for twenty years, the joints were first made 1 inch wide and filled with screenings grouted with tar, the whole being finished with a dressing of coarse sand and tar $\frac{3}{4}$ inch thick spread over the entire surface. All the wood pavements originally laid in Sydney were entirely renewed in 1893, the thoroughfares being relaid with black butt and tallow wood.*

The hard wood blocks are now laid in that city with close joints. They are previously dipped in tar and hammered up at every twelfth row, the surface being flushed over with boiling tar and sand. In some instances the blocks are dipped twice in boiling tar and stacked to allow the surplus tar to drain off before they are laid.

471. The close joints of wood pavement grouted with pitch are of an elastic nature, which admits of their yielding to the expansion of the wood, thus preventing lateral pressure being transmitted to the channels or kerbs, and securing that the arrises of the courses do not become worn and rounded. This latter defect, inseparable from a pavement laid with wide joints, forms a corrugated or corduroy surface, which has the disadvantage of becoming noisy and dirty, and reduces the life of the pavement considerably.

Portland cement grout requires at least $\frac{1}{4}$ inch space between the rows to form a joint, and, being a rigid material, is not capable of yielding to local expansion of the wood blocks, hence under certain circumstances the pressure is transmitted to the channels, and may displace the kerbstones in the manner mentioned. The vibration created by heavy wheel traffic at times loosens the blocks of a wood pavement which has been jointed with cement grout, thus destroying its imperviousness.

472. There is one distinct property which characterizes a joint grouted with cement, and that is, it can be formed in any weather, except during frost, which is an advantage towards facilitating the progress of the work; on the other hand, it requires at least six clear days to properly set, which is a great disadvantage in most cases. The grout is generally composed of Portland cement mortar in the proportion of one of cement to three of sharp clean river sand, the cost of which is, for the width of joint mentioned, about 6d. per square yard of paving.

473. The cement grouting on wood blocks has a tendency to set up dry rot, which can only be accounted for by the chemical action which takes place between the two materials in the joints of the paving. This is

* "Hard Wood Pavements in Sydney, New South Wales," by Mr. R. W. Richards, City Engineer, Sydney, *Proc. Assoc. Municipal and County Engineers*, vol. xxiii.

a matter of considerable importance which should not be lost sight of. Cement grouting makes a wood pavement much more noisy than one formed with a pitch composition which is of a slightly elastic nature. The arrises of the blocks, especially in wide-jointed pavements, becoming worn or rounded, the cement filling is exposed, which soon becomes disintegrated by the action of the horses' feet.

As bearing on the matter of dry rot in wood paving, the following interesting practical observations on the subject may be given * :—

"It is worthy of mention that while the above contracts were being carried out (construction of two new thoroughfares, viz., Martin Place and Queen Street, Sydney, 1894) it was necessary to remove some of the old blocks from the adjoining streets in order to make proper junctions with the new works, and, in doing so, it was observed that the effect of a cement joint on the timber was most injurious, while a bituminous joint acted as a preservative. Two cases met with, are deserving of special attention.

"(*a*) At one end of Queen Street it was necessary to remove a considerable area of pavement which had been laid six years, in which a cement joint had been adopted, the width of joint being maintained by iron studs projecting $\frac{3}{8}$ inch from the face of the block; here it was found that dry rot had set in wherever the wood had been in contact with the cement. Different kinds of timber had been used, but every block was more or less affected. On this being observed, other portions of the pavement which had been similarly constructed were examined, but all were found to be in the same state; a microscopical examination of the timber thus affected showed no signs of fungoid growth. It is therefore assumed that the dry rot was a decomposition of the timber brought about by chemical action—such as combination of the oxygen in the cement with the carbon in the wood, forming carbonic acid gas.

"(*b*) At the other end of Queen Street, where blocks were removed which had been laid eight years, in which the joints had been caulked with a mixture of tar, pitch and basalt screenings, the timber was found to be in a perfect state of preservation; and although the road had sustained a daily traffic of approximately 25,000 tons for eight years, it was in almost as good a state as when first laid. The blocks, which were originally 6 inches deep, made a perfect junction with the new 6 inch blocks, the greatest wear observable in the old blocks after eight years' service being $\frac{1}{10}$ inch."

474. When pitch grout is adopted as the material for forming the joints, the blocks can be laid practically close or with a space not exceeding $\frac{1}{10}$ inch in width, which, besides making an impervious and more durable pavement, prevents the spreading of the fibre of the wood, and admits of a smooth

* "On Australian Hard Wood for Pavements," by W. A. Smith, M.I.C.E., *Minutes of Proc. of C. E.*, vol. cxvi. p. 264.

surface being retained; while the facility for cleansing the pavement is greatly increased.

475. The bituminous composition being of a slightly elastic nature, absorbs and equalizes the expansion of the blocks; it also acts as a preservative to the wood. One disadvantage, of which mention has been already made, is that the joints must be made only when the wood is thoroughly dry, wet weather being detrimental to its use. Under these circumstances it is usual to cover over the pavement with tarpaulins. As the bituminous grout hardens almost immediately after the joints are filled, traffic may be allowed to pass over the pavement on the completion of the work. Special travelling boilers are generally employed for preparing the pitch and creosote oil composition; the mixture, when of a proper consistency and in a boiling state, is drawn off in suitable buckets, or into wheeled carriers, transported to the pavement under construction, and poured into the joints. The usual method (already described) is to dip the blocks into the boiling mixture, then lay them in position close together. Pitch grouting, with a $\frac{1}{10}$ inch joint, costs about 7d. per square yard of paving.

476. **Expansion Joints.**—When wood pavements were first introduced into the principal towns in this country, it was the custom to allow a wide expansion joint at the kerbs or channels at each side of the carriageway. This arrangement was necessary, partly owing to the use of untreated wood, partly to the wide joint between the blocks, and partly to those joints being grouted with cement. By creosoting the deal blocks and by extending the use of hard woods as a paving material, the necessity for a wide expansion joint has been to a great extent obviated. The earlier wood pavements generally had an expansion joint at the channels of 1 inch for every 8 or 10 feet in width of thoroughfare; this, however, has been gradually reduced, and at the present time an allowance of $1\frac{1}{2}$ to 2 inches on each side of a 60 foot roadway is considered sufficient for hard wood pavements when the blocks are jointed with pitch grout. The expansion joints are filled up in a variety of ways, sand, loam, and clay being the material which was used to a considerable extent in the earlier pavements; but these joints are now in most instances filled with a hot mixture of pitch and creosote oil, similar to that used in forming the joints of the pavement. Fig. 125 shows a cross-section of a wood pavement.

477. The merits and demerits of close and wide joints, from a maintenance and sanitary point of view, and as affording a good foothold for horses, has in recent years been carefully investigated, and practical deductions have been drawn from the observations made.

The generally accepted opinion—that wide joints afford greater safety for horses travelling over the pavement on a level or comparatively level roadway—is not borne out by actual experience in the use of these differently constructed pavements. Where wide joints have been adopted the effect of

the hoof and wheel traffic has been to spread and disintegrate the fibre of the wood blocks, rounding the edges and forming a corduroy surface. This evil increases with the width of the joint, and as a consequence the pavement is reduced to a state of disrepair long before the blocks are worn out, and the life of the pavement is materially reduced.

Unnecessarily wide joints retain a large quantity of dirt, produce a noisy pavement, and increase the expense of cleansing the surface. Imperfect scavenging of a wood pavement produces a greasy film on the surface in dry weather and slimy slop after rain, consequently the pavement becomes slippery. This serious defect can only be effectively obviated by washing the carriageway with water and the occasional application of sand to render it

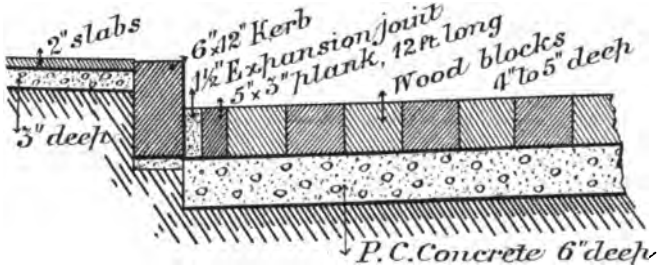


FIG. 125.—Cross-section of wood pavement.

fit for either pedestrian or vehicular traffic. When these objectionable conditions exist, combined with the disagreeable odours emitted under such circumstances, they add greatly to the discomfort of those using the thoroughfare. The essentials for a satisfactory wood pavement may be summarized thus: it should be properly constructed, carefully maintained and renewed at frequent intervals, and efficiently scavenged.

478. The relative lifetime of soft and hard woods as paving materials cannot as yet be given with that certainty which in the light of longer experience will be made possible. On many of the thoroughfares in London subject to heavy and continuous traffic where soft wood has been in use for a number of years, the actual life or duration of the pavement, before renewal becomes necessary, is considered to be from seven to eight years. The first pavement of Australian hard wood has only been in use since 1889, and is at the present time in good condition, so that the life of this class of paving material may be estimated as at least twelve years.

In Sydney, New South Wales, the lifetime of the hard woods, such as black butt and tallow wood, on carriageways subject to very heavy traffic is considered to be twenty-one years. "In one of the busiest thoroughfares of that city where wood blocks were laid thirteen years ago (1881) and which are at the present time (1893) in a perfect state of preservation, the blocks have only been worn down $\frac{9}{16}$ inch; judging from their present condition, there

appears to be no reason why they should not do good service for another ten years." *

It is also stated that Queen Street (Sydney), paved with wood and sustaining a daily traffic of approximately 25,000 tons, showed $\frac{11}{16}$ inch as the gross result of eight years' wear (when some of the blocks were removed). This thoroughfare is 100 feet wide and situated on gradients of 1 in 22 and 1 in 24. The yard tonnage is therefore approximately 256,000 tons per annum.

Later carriageway pavements in Sydney † "laid upon a good foundation of concrete with New South Wales hard woods, with slape or butt joints, with convexity of 1 in 60 or 1 in 80, as the longitudinal gradient may suggest, properly cleansed and maintained, is the best and most suitable form of pavement for heavy and continual traffic; and that the best timbers for such work are tallow wood, black butt, blue gum, red gum and mahogany. These timbers, having been so laid in Sydney streets, have, upon examination, shown wear at the rate of from $\frac{1}{60}$ to $\frac{1}{80}$ inch per annum, and have not required repairs of any kind whatsoever. The cost of the first wide jointed pavement, including all labour, materials, etc., was about 27s. per yard super., while recently, pavements with the close joints in Sydney cost 15s. 6d. per yard." This difference in cost is accounted for by the greater quantity of pitch in the wide joint, the consequent larger amount of labour required, and the higher wages paid for laying the blocks when first introduced.

"Twenty-one hours' observation show that 350 vehicles per hour pass at King and George Streets, Sydney, with a width of carriageway of 36 feet. On a width of 74 feet in George Street South, they pass at the rate of 500 vehicles per hour, and you can estimate each vehicle as representing one ton on an average."

It will be apparent, from the relative wear of deal and hard wood pavements in the towns of this country, as indicated by the statistics now available, that the Australian hard woods last longer when the blocks are laid close together with impervious joints. It is, of course, generally admitted that the life of Australian hard woods is considerably longer than that of deal, but much depends on the method adopted in laying the pavement, the amount and weight of traffic passing along the thoroughfare, the gradient and other circumstances of a local nature.

479. The amount of wear of hard wood paving blocks in different thoroughfares in the city of London, with the approximate extent and class

* "Australian Hard Woods for Pavements," by Mr. W. A. Smith, M.I.C.E., *Proc. Inst. Civ. Engineers*, vol. cxvi. p. 266 (1894).

† "Hard Wood Pavements in Sydney, New South Wales," by R. W. Richards, A.M.I.C.E., *Proc. Assoc. Municipal and County Engineers*, vol. xxiii.

of the traffic passing over them, and also the comparative wear where a soft wood paving had previously existed, will now be given.

Observations made on the wood pavement in Westminster Bridge Road showed that the amount of wear of the Jarrah blocks was, during a period of seven years, equal to from $1\frac{1}{16}$ inch to $1\frac{1}{8}$ inch, or about $\frac{1}{7}$ inch to $\frac{1}{8}$ inch annually.*

The traffic going towards Westminster over this thoroughfare is given as 334 tons per foot in width of road in twelve hours, from 6 a.m. to 6 p.m. (see Nos. 1, 7, and 8, in Table XLIX.).

The following detailed statistics on the wear of hard wood paving and the weight of traffic passing over several carriageways in the Vestry of St. Pancras, London, give most valuable information on the subject. †

"Between February 23 and March 11, 1893, a portion of the western end of Euston Road was repaved, and, with the special object of proving the durability of the different timbers employed, the length in question was paved in four blocks. From the line of the south side of Southampton Street, a length of 63 feet was paved with Jarrah, the next length of 63 feet was paved with yellow deal, the next length of 62 feet was paved with Karri, and a closing length of 49 feet with yellow deal."

"The wear upon these different lengths has been recently measured (1896) and may be taken as at three years from the date of laying. It proves to be $\frac{1}{4}$ inch on the Jarrah, $\frac{1}{4}$ inch on the Karri, and $1\frac{3}{8}$ inch on the deal blocks. These measurements were taken in the centre line of traffic, where the wear might be regarded as greatest, and at about the centre of each length of wood. It was found that the reduction in depth was the same on both sides of the road. These figures are equivalent to $\frac{1}{12}$ inch per annum on the Jarrah and Karri, and $1\frac{1}{12}$ inch on the deal, and the relative rates of wear are as 1 to 6."

"The results (record of the traffic during seven days, July 1895) showed that during the seven days, 110,977 tons of traffic, *i.e.* vehicles and their loads, not including horses, passed along this portion of the road; this may be taken as equal to 5,770,800 tons per annum, or 575,544 tons per yard in width per annum. The omnibus traffic during the week amounted to 8575 tons, or 7·72 per cent. of the total traffic.

"Observations both as to wear and traffic were also obtained upon another length of Euston Road, at St. Pancras Church. This portion of the road was paved with Jarrah blocks between April 30 and May 24, 1894. The road has therefore been under traffic for say $1\frac{3}{4}$ years, and the wear has

* "Hard Wood Paving," by J. P. Norrington, A.M.I.C.E., Engineer and Surveyor, Lambeth Vestry, London, *Proc. Assoc. of Municipal and County Engineers*, vol. xxii.

† "Wear of Hard Wood Paving and the Weight of Traffic thereon," by W. Nisbet Blair, A.M.I.C.E., Vestry Surveyor, St. Pancras, *Proc. Assoc. of Municipal and County Engineers*, vol. xxii., 1895–96.

been very carefully measured upon an opportunity afforded by a water trench which completely crossed the road from kerb to kerb. The blocks were exactly 5 inches deep when laid, and the wear is shown upon the diagram, the greatest reduction being $\frac{5}{16}$ inches at 12 feet from the kerb on the south side, and $\frac{3}{16}$ inches at about the same distance from the north side. The greatest wear is therefore ·18 of an inch, or less than $\frac{1}{5}$ inch per annum.

"The record of traffic taken near this trench, at a point where the road is 38 feet 4 inches wide, shows that during seven days from August 26 to September 2, 1895, 101,063 tons passed in the week, or 5,255,276 tons per annum, or 411,318 tons per yard in width per annum. The weight of omnibus traffic included in the above is 32,113 tons per week, which is equal to 31·8 per cent. of the total weight of traffic. The total number of vehicles during the week was 67,153, of which 12,677 were omnibuses, their proportion being 19·0 per cent. of the total number.

"The author has referred to weight of omnibus traffic as distinct from the remainder, as he believed that the effect of omnibus traffic upon a roadway is very much greater than an equal weight of general traffic, and it remains to be seen whether the second instance described, with 31·8 per cent. of omnibus traffic, wears better or worse than the first case, where omnibus traffic is only 7·72 per cent., though the total traffic is 40 per cent. greater in the first case than in the second."

Other thoroughfares in the St. Pancras district have been paved with Jarrah, over which the traffic is very considerable; the wear, it is stated, does not appear to have been as much as $\frac{1}{4}$ inch; the amount of traffic has not, however, been recorded in these instances.

Further interesting figures in tabular form relative to the wearing capacity of hard wood paving are also given, referring to some of the thoroughfares in the Lambeth Vestry,* already mentioned.

* "Hard Wood Paving," by J. P. Norrington, A.M.I.C.E., Surveyor, Lambeth, *Proc. Assoc. of Municipal and County Engineers*, vol. xxii.

TABLE XLIX.

Wood.	Locality.	Date Laid.	Years' Wear.	Loss.	Loss per Annum.
1. Jarrah, .	Westminster Bridge Road, .	May 1889	Nearly 7	1⅛ in.	·1607 in.
2*a*. Karri, .	Crossing Lower Marsh, 6 feet from side,	Nov. 1890	5½	¼ ,,	·045 ,,
2*b*. ,, . .	Crossing Lower Marsh, centre,	,,	5½	1/16 ,,	·01126 ,,
2*c*. ,, . .	Crossing Lower Marsh, 6 feet from opposite side,	,,	5½	5/16 ,,	·0337 ,,
2*d*. Jarrah, .	Lower Marsh, 6 feet from side,	,,	5½	¼ ,,	·045 ,,
2*e*. ,, . .	Lower Marsh, centre, . .	,,	5½	¼ ,,	·045 ,,
2*f*. ,, . .	Lower Marsh, 6 feet from opposite side,	,,	5½	⅛ ,,	·02275 ,,
3. Blue gum, .	Waterloo Road (beyond Station),	Oct. 1894	16 mths.	1/16 ,,	·047 ,,
4. Black butt,	Do. do., .	Sept. 1895	5 ,,	Nil.	Nil.
5. Stringy bark,	Do. do., .	Oct. 1894	16 ,,	1/16 in.	·047 ,,
6. Jarrah, .	Lambeth Walk, . . .	Sept. 1889	6½	5/8 ,,	·05769 ,,
7. ,, . .	Westminster Bridge Road, .	May 1889	Nearly 7	1⅛ ,,	·1607 ,,
8. ,, . .	Do. do. do., .	,,	,,	1 1/16 ,,	·15178 ,,

Observations have been made by Mr. C. Mason, Surveyor, St. Martin's Vestry, London, in the Strand, at West Strand Post Office, where yellow deal, which had been previously laid, was worn down 4½ inches in twelve months. This particular portion of the thoroughfare is a stopping-place for omnibuses, which pass there to the number of between 300 to 400 per hour, and it is subjected to an enormous amount of hoof and wheel traffic, besides the injurious effect resulting from skidding the wheels of these vehicles.

The yellow deal pavement at this point was replaced with Jarrah first and then Karri wood, the former being worn down to the extent of ¾ inch per annum, while the latter timber is being reduced by wear at the rate of ⅕ inch annually. In another part of the Strand, near Exeter Hall, Jarrah is worn down ¼ inch per annum, while the yellow deal which it replaced lost 2½ inches in four years or ⅝ inch annually.

480. In the following table,* prepared and classified by G. H. Stayton, the additional information in regard to the total amount of traffic passing over the particular thoroughfare reduced to a standard is given, along with the comparative wear and other particulars relative to soft wood pavements.

* *Minutes Proc. Inst. Civ. Engineers*, vol. lxxviii., Part 4, p. 280.

TABLE L.

Situation.	System.	Weight per yard width per day of 16 hours.	Depth of annual wear of wood.	Comparative annual wear of wood as reduced to a traffic standard of 750 tons per yard width per diem.
		Tons.	Inch.	Inch.
1. Fleet Street, .	Asphaltic, . . .	1360	0·456	0·251
2. Ludgate Hill, .	Improved, . . .	1236	0·428	0·259
3. Oxford Street, .	Henson's (East Section),	1191	0·191	0·120
4. Fleet Street, .	Henson's, . . .	1165	0·269	0·173
5. Oxford Street, .	Plain, ...	1164	0·475	0·306
6. ,, ,, .	Asphaltic, . . .	1137	0·484	0·319
7. Parliament St.,	Improved, . . .	1106	0·154	0·104
8. Leadenhall St.,	Henson's, . . .	1000	0·264	0·198
9. Oxford Street, .	,, (West Section),	985	0·329	0·250
10. ,, ,, .	,, (Central), .	948	0·323	0·255
11. Leadenhall St.,	Improved, . . .	808	0·200	0·186
12. Brompton Rd.,	Asphaltic, . . .	648	0·373	0·431
13. King's Road, .	Improved, . . .	603	0·157	0·195
14. Brompton Rd.,	Henson's, . . .	584	0·184	0·236
15. Edgeware Rd.,	Plain, ...	584	0·198	0·254
16. Regent Street, .	Asphaltic, . . .	558	0·286	0·384
17. ,, ,, .	Lloyd's, . . .	558	0·214	0·288
18. King's Road, .	Improved (pitch pine), .	558	0·089	0·119
19. ,, ,, .	Plain	551	0·144	0·196
20. ,, ,, .	Plain (asphalte bed), .	498	0·139	0·209
21. ,, ,, .	Plain (pitch pine), .	468	0·055	0·088
22. ,, ,, .	Creosoted blocks (mastic joints), . . .	434	0·139	0·240
23. ,, ,, .	Creosoted blocks (lime joints), . . .	407	0·111	0·204
24. Sloane Street, .	Plain, ...	279	0·065	0·175

In the course of a few years positive information as to the relative wearing capacity of the Australian and the other hard woods now employed will be available, when a more direct comparison of the life and ultimate cost of the different descriptions of wood used for carriageway pavements may be expected.

481. Cost of Wood Pavements.—The cost of laying a soft or hard wood pavement depends on circumstances, the work being for the most part carried out by contract; only in a few instances is the timber bought at so much per load, cut by machinery into blocks of suitable size, and the work carried out by the local administration. The price of yellow deal cut to size varies from £6 to £7 per 1000 blocks, and for Jarrah and Karri from about £6 to £8 per load, although the prices fluctuate considerably at times. The number of blocks, 3 inches by 5 inches by 9 inches, which can be cut from a load is estimated at 640, and, including handling and cost of cutting, the price may be taken at from £10 to £11 per 1000 blocks for Jarrah, and 5s. less for Karri. The cost of the pavement is, however, generally stated at so

much per square yard, and may vary from 7s. to 8s. for deal, and from 11s. to 13s. for Australian hard wood laid on existing foundations. These prices are further influenced by the method adopted in laying the paving, width of joint, and the description of material used, as may be gathered from Table LII.

A very complete and interesting summary of statistics of actual cost relative to hard wood paving laid in the Lambeth district is given by Mr. Norrington,* which also gives the area paved and date when laid in different thoroughfares, Table LI.

TABLE LI.

Showing particulars of certain wood pavements in London.

Locality.	Area in square yards.	Date laid.	Cost of work.			Cost, per yard super.		Remarks.
			£	s.	d.	s.	d.	
Westminster Bridge Road, .	1,960	1889	1,096	11	9	11	8½	New, replacing macadam.
Lambeth Walk, . . .	4,956	1889	3,095	6	1	12	6	Ditto.
Lower Marsh, etc., New Cut,	8,723	1890	5,254	9	1	12	0½	Ditto.
Oakley Street, . . .	3,656	1890	2,216	9	0	12	1½	Ditto.
Brixton Road, Brixton Hill (part of), Kennington Park Road (part of), .	31,175	1891–3	23,944	0	0	15	4½†	Ditto.
Stamford Street, . . .	4,700	1892	2,623	8	3	11	2	Relay, replacing deal.
York Road, ...	7,000	1893	3,952	5	7	11	3½	Ditto.
Brixton Hill (part of), . .	1,112	1893	798	19	10	14	4½	New, replacing macadam.
Albert Embankment, Lambeth Road, . .	5,474	1893	3,676	2	9	13	5½	Relay, replacing deal.
Westminster Bridge Road, .	7,010	1894	4,159	5	3½	11	10	New, replacing macadam.
Kennington Road, . .	21,878	1894	14,084	4	6½	12	10½	Ditto.
Waterloo Road (part of), .	1,014	1894	522	7	7	10	3½	Jarrah, stringy bark and blue gum, relay part, and part new.
Upper Kennington Lane, .	10,352	1894	8,153	0	0	9	1	Relay, replacing deal.
Lower Kennington Lane, .	7,574	1895						
Waterloo Road, . . .	12,435	1895	6,512	2	1	10	6½	Part new and part relay.
Kennington Park Road, .	4,338	1895	2,801	12	6	12	11	New, replacing macadam.
Clapham Road, . . .	16,295	1895–6	10,863	16	8	13	4	Ditto.
	149,652							

* "Hard Wood Paving," by J. P. Norrington, A.M.I.C.E., Vestry Surveyor, Lambeth, London, *Proc. Assoc. of Municipal and County Engineers*, vol. xxii.

† This includes cost of relaying footpaths, etc.

TABLE

NAME OF TOWNS.	First cost per square yard.	Kind of foundation and size of paving blocks in inches.
1. London—Hammersmith, .	14s. 2d. including foundation.	P. c. concrete 6 in. deep, 3×5×9, J., B.
,, Holborn, . . .	14s. 9d. ,,	P. c. concrete 6 in. deep, 3×5×9, J.
,, Lambeth, . .	12s. to 14s. ,,	,, 6 ,, 3×4½×9, J.
,, Mile End, Old Town,	(Not any.)	.. .. ..
,, Shoreditch, . .	14s. ,,	P. c. concrete 6 in. deep, 5 in. deep, J.
,, Stoke Newington, .	14s. 9d. hard, 11s. 5d. soft.	,, 6 ,, 3×4 and 5×9, J. and Y. D.
,, Strand, . . .	8s. on old foundations.	P. c. concrete 12 in. deep, 3×6×9, R. W.
,, St. Martin's-in-the-Field, Charing Cross, . . .	10s. ,,	P. c. concrete 6 in. deep, 3×5×9, mostly Y. D.
,, St. Mary, Islington,	10s. to 12s. hard, 7s. 6d. to 9s. soft on old foundations.	P. c. concrete 6 to 7 in. deep, 3×4½, J. and Y. D.
,, St. Pancras, . .	13s. 6d. including foundation.	P. c. concrete 6 in. deep, 3×5×9, J. K.
,, Whitechapel, .	11s. hard, 9s. soft on old foundation.	P. c. concrete 6 in. deep, 3×5×9, J., Y. D.
2. Glasgow, ...	12s. 6d. to 16s. including foundation.	P. c. concrete 6 in. deep, 3×5, J., K., P. P.
3. Liverpool, ...	13s. 6d. to 18s ,,	P. c. concrete 6 in. deep, various.
4. Manchester, ...	14s. to 15s. ,,	,, 6 ,, 3×6×6 to 11, B.
5. Birmingham, ...	11s. on old foundations.	P. c. concrete 6 in. deep, 3×6×9, Y. D.
6. Sheffield, ...	11s. 6d. ,,	P. c. concrete 6 to 9 in. deep, 3×6×9, mostly Y. D.
7. Belfast, ...	(Not any.)	.. .. ..
8. Bristol, ...	17s. 6d. hard, 11s. soft, including foundation.	P. c. concrete 6 in. deep, 3×5×9, J., K., O., Y. D.
9. Edinburgh, ...	17s. hard, including foundation.	P. c. concrete 6 in. deep, 3×5×9, J., K., T.
10. West Ham, ...	15s. 6d. including foundation.	P. c. concrete 6 in. deep, 5 in. deep, J.
11. Dublin, ...	13s. ,,	,, 6 ,, 3×5×7, R. W.
12. Bradford, ...	17s. 6d. hard, 12s. 6d. soft, including foundation.	P. c. concrete 6 in. deep, 3×5×9, J., R. W.
13. Newcastle-upon-Tyne, .	15s. including foundation.	P. c. concrete 6 in. deep, 3×6.
14. Leicester, ...	14s. 6d. ,, ,,	,, 6 ,, 4 in. deep, K.
15. Bolton, ...	12s. 6d. ,, ,,	,, 6 ,, 3×6×9, Y. D.
16. Dundee, ...	(Not any.)	.. .. ..
17. Aberdeen, ...	(Do.)	.. .. ..
18. Birkenhead, ...	.. .. ..	.. .. ..
19. Southampton, . . .	14s. hard, 9s. 6d. to 10s. 6d. soft, including foundation.	P. c. concrete 6 in. deep, 4×5, J., Y. D.
20. Wolverhampton, . . .	.. .. ..	.. .. ..
21. Coventry, ...	(Not any.)	.. .. ..
22. Bury, ...	13s. including foundation.	P. c. concrete 6 to 9 in. deep, 3×5, B.
23. Hanley, ...	12s. ,, ,,	,, 6 in. deep, 3×5, B.

REFERENCE TABLE AS TO DIFFERENT

B. Beech. J. Jarrah. K. Karri. O. Oak. P. P. Pitch Pine.

* This table is compiled from different sources, chiefly from Articles

LII.*

Description of grouting.	Annual cost of maintenance per square yard: (a), repairs; (b), cleansing and watering. (a)	(b)	Estimated life of wood paving under heavy traffic.	Remarks.
Dipped in pitch and creosote oil, and laid with close joints.	First 5 or 6 years nil, afterwards will vary from ½d. to 2d.		J., 12 years.	
Bituminous pitch.	.. ..	.. ..	About 30 years.	
Pitch and creosote.	.. ..	.. ..	Laid for 10 years.	In good condition (exceedingly heavy traffic).
.. ..	.. ..	.. ..	.. ..	
Blocks dipped in bituminous mixture, grouted with P. c. grout.	.. ..	.. ..	Not yet ascertained.	
Pitch and P. c. grout for hard wood; P. c. grout for soft wood.	¾d.	2d.	8 to 10 years.	Maintenance cost estimated for first three years.
Bituminous mastic and P. c. grout.	1s.	.. ..	8 to 10 years.	Blocks dipped in creosote before using.
Pitch, tar, and P. c. grout.	.. ..	.. ..	5 to 12 years.	Soft wood creosoted 5 years in Strand; heavy traffic.
Bituminous.	.. ..	.. ..	Deal 6 to 8; J. probably 10 years.	
Pitch and creosote oil.	.. ..	.. ..	6 years old (laid beginning of 1893).	Heavy traffic; received first repair 1899.
Pitch, tar, and naphtha.	.. ..	4½d.	Soft wood, 4 years; hard, 8 years.	
Bituminous.	.. ..	.. ..	About 6 years.	
Pitch and creosote oil.	Varies.	Varies.	10 to 15 years.	
Pitch, tar, and sand.	4d.	.. ..	15 years.	Blocks creosoted and reversed after being worn.
Portland cement.	7d. to 9d.	4d.	10 years.	(a) Under contract for 21 years, including all repairs.
Dipped in pitch and grouted with P. c.	.. ..	.. ..	7 to 10 years.	
.. ..	.. ..	.. ..	.. ..	
Dipped in tar and grouted with P. c.	10d.	.. ..	About 8 years.	Heavy traffic.
Asphaltic or cement.	.. ..	.. ..	About 12 years.	
Pitch.	.. ..	.. ..	.. ..	Only been laid a short time.
Asphaltic and cement.	.. ..	.. ..	About 8 years.	Paving been down from 7 to 11 years without much repairs.
Pitch, tar, and grouted with cement and chippings.	.. ..	.. ..	Soft 7 years, hard 14 years.†	†Expected to last these number of years.
Boiling pitch and tar.	.. ..	.. ..	About 12 years.	
Pitch and tar.	.. ..	.. ..	Soft wood 7 years, hard wood 12 years.	Jarrah, and deal also used, creosoted.
P. cement and fine gravel.	6d.	.. ..	10 years.	
.. ..	.. ..	.. ..	.. ..	
.. ..	.. ..	.. ..	.. ..	
.. ..	.. ..	.. ..	.. ..	Laid only to a limited extent; too small for comparison.
Pitch and tar, and P. cement.	.. ..	4d.	.. ..	Not long enough down to give results. One section under light traffic, and renewed after 16 years.
.. ..	.. ..	.. ..	.. ..	Only recently laid, information therefore not available.
.. ..	.. ..	.. ..	.. ..	
Pitch and P. cement.	.. ..	.. ..	15 years.	Blocks creosoted.
Creosoted oil and pitch, and P. cement.	.. ..	.. ..	12 ,,	Ditto.

Kinds of Wood Employed.

R. W. Red Wood. T. Tallow Wood. Y. D. Yellow Deal.

in *The Municipal Engineer and Surveyor*, by Mr. H. Richardson (1899).

The particulars given in Table LII. show in a comprehensive manner the class of wood used and the method adopted in forming the joints in laying wood pavements in the principal cities and towns in the kingdom, with the cost and amount of annual repairs and the life of the paving blocks so far as can be obtained. The towns are arranged according to the population.

482. From the figures given in the preceding table it appears that the average life of soft wood paving in the busiest thoroughfares in London is about 6½ years, and for Australian hard woods, which are not worn out yet, it is estimated at ten years. The cost of paving, assuming the existing foundations to be sufficient, is 8s. for deal, and 11s. for Australian hard woods per square yard.

The annual expenditure for repairs during the lifetime of the pavement must necessarily be a variable item, although it must obviously be less for hard wood paving, but in the following calculation it may be assumed to be the same in order to allow of comparisons.

The relative wear and annual cost of pavements, taking the life or service of soft wood at seven years, and Western Australian hard woods at twelve years, exclusive of annual repairs and cleansing, will therefore be as follows.

Soft Wood Pavements.	First cost 8s. per square yard (exclusive of foundations), life service 7 years.	First cost per annum during life of pavement.
		13·23d. per square yard.
Hard Wood Pavements.	First cost 11s. per square yard (exclusive of foundation), life service 12 years.	First cost per annum during life of pavement.
		11·0d. per square yard.

This clearly shows a saving in favour of hard woods, and that economy may be effected by paying a higher price for a more durable material, as also that a hard wood pavement with twelve years' life, estimated by wear, is equivalent to a soft wood pavement having seven years' service.

Table LIII. gives the total expenditure and amount of the average annual payments on the first cost of the work, but exclusive of foundations, repairs, and cleansing, for soft and hard wood pavements on a carriageway 1 mile long and 40 feet wide.

TABLE LIII.

Description of wood pavement.	One mile of roadway, 40 ft. in width, area in square yards.	Price per square yard.	Total cost.	Duration of pavement.	Average annual cost of repayment of loan at 3½ per cent. spread over period of duration of wood.
Deal creosoted, 3 in. × 5 × 9,	23460·8	8s.	£9884·32	7 years.	£1270 2 7
Jarrah, 3 in. × 5 × 9, . .	23460·8	11s.	12903·44	12 years.	883 17 7

If the repairs and cleansing be taken into account there can be no doubt as to there being a further considerable annual saving in the case of hard wood, and although the first cost is greater, hard wood pavements are less expensive in the long run, particularly where vehicular traffic is heavy. In addition to this there is a considerable advantage, especially in busy carriageways, of the thoroughfare being less frequently closed for renewals, which is a matter of great importance to business people, shopkeepers and others.

CHAPTER XI.

ASPHALTE PAVEMENTS.

483. Asphalte pavements for carriageways were introduced into London in 1869, having been used in Paris as early as 1854, where their application became general in 1867.

The principal sources of supply of bituminous or asphaltic rock, which is a natural stone consisting of fine carbonate of lime impregnated with bitumen or mineral pitch of a liver brown colour, are Val de Travers, in Switzerland; Seyssel, in France; Limmer, in Hanover; and also some Sicilian mines. The pitch lake in Trinidad supplies the bitumen from which the best artificial asphaltes are made.

The asphalte chiefly used for carriageway pavements in Europe has hitherto been obtained from Val de Travers and Limmer; that made from Trinidad pitch, although more or less a failure when first introduced into this country, is now being extensively laid in London, and that it is the composition best suited for withstanding the heavy and continuous wheel traffic and climate appears now to have been satisfactorily determined.

484. In Canada and the United States, Trinidad asphalte only is used in the principal cities and towns; over 30 million square yards have been laid, the length of carriageways so paved being approximately 2000 miles.

It appears strange to remark, as already observed, that the earlier Trinidad asphaltic pavements in Europe were not successful, and also that the thoroughfares laid in Washington, U.S.A., made from European bituminous limestone, were likewise failures.

The latter kind of pavement, laid in Pennsylvania Avenue and other thoroughfares in Washington, was, after a few years' wear, replaced by Trinidad lake asphalte, which has remained for a considerable period of time in an efficient and smooth condition.

485. These pavements are now laid only in a compressed form, mastic asphalte (as generally understood), which was used for carriageways at one time, being now a thing of the past. In the bituminous rock pavements the material is first broken to about 3-inch cubes, then pulverized by being

passed through a disintegrator and reduced to a fine powder, which will pass through a sieve having a mesh equal to 0·10 of an inch. In this condition it is ready for use, but it has to be heated before being applied to form the street covering.

In the case of Trinidad asphalte, the crude bitumen obtained from the pitch lake is refined so as to eliminate the water and vegetable matter contained in it. This refined bitumen, which becomes hard when cool, is converted into 'asphaltic cement,' by adding a small quantity of residuum oil of petroleum, which gives the mixture a certain amount of plasticity. This, added to sand and powdered limestone, forms the asphaltic composition. It cements these ingredients together when mixed hot, the proportions being regulated according to the quality of the 'asphaltic cement' and the character of the sand; if this is of a suitable nature, the limestone dust is dispensed with altogether. The climate of the particular town in which the pavement is to be laid has also a considerable influence on the relative proportions of the ingredients in the mixture.

Generally the proportions may be taken as follows:—

Asphaltic cement,	14 to 17	per cent.
Sand,	81 to 68	,,
Stone dust,	5 to 15	,,
	100 100	,,

486. Contour and Gradients.—As asphalte pavements are extremely smooth, surface water is easily drained from the thoroughfare; consequently, an excessive rise, or even the amount generally given to a pitched or wooden pavement, is unnecessary, a rise of about $\frac{1}{80}$ to $\frac{1}{100}$ of the width of the carriageway being in most circumstances sufficient. It is not advisable to lay a limestone rock asphalte pavement steeper than 1 in 50 or 1 in 60, and Trinidad asphalte 1 in 25. On steeper gradients they afford but little foothold for horses, and are consequently not safe to travel over.

487. Foundations.—A solid unyielding foundation is indispensable for all asphaltic pavements. It should be laid in a similar manner to that described for a pitched or wooden pavement. Considering that the thickness of the asphalte is only about 2 inches, it is essential that the concrete be of first rate quality; while in some cases the depth may be advantageously increased to 9 inches to the desired contour, and floated with cement mortar.

488. Compressed asphalte has hitherto been the name applied to bituminous limestone rocks which are reduced to a powder, then laid on the concrete foundation, rammed with punners and subsequently rolled until thoroughly compressed. Trinidad asphalte is treated in a similar manner by being compressed first with light rollers, and subsequently with heavier ones. Specifications now generally state that the work is to be of rock

asphalte or Trinidad asphalte, as a means of distinguishing these different materials, both of which are compressed pavements.

489. The natural rock for carriageway pavements consists of carbonate of lime and mineral bitumen in variable proportions, that containing from 7½ to 12 per cent. of the latter being best suited for paving purposes. Should the asphalte contain less bitumen than 7 per cent., it becomes too brittle and is liable to crack; therefore it is deficient in binding properties. If the proportion is greater than 12 per cent., the asphalte will be too soft, and, consequently, easily affected by solar heat.

The specific gravity of bituminous limestone asphalte varies according to the proportion of the bitumen it contains, but the average may be taken as 2·25, and the weight of a cubic yard 3874 lbs.

The method of carrying on the operations of laying rock asphalte is to heat the powder in revolving cylinders to a temperature of about 280° Fahr., in order to evaporate the superfluous moisture, care being exercised to keep the particles as free as possible, so that they will remain separate without being calcined. Asphaltic rock containing from 9 to 10 per cent. of bitumen is that most suitable in all circumstances. The powder thus heated is conveyed to the carriageway, where the asphalte pavement is to be formed, in iron covered carts, this being necessary, so that it may not lose more than twenty degrees of heat during transit and may retain its property of adhering under compression.

490. As the surface of the concrete foundation must be perfectly dry when the asphaltic powder is spread upon it, this work can only be accomplished during suitable weather. Dryness is absolutely essential, as the best asphalte laid upon damp concrete draws up the moisture, which is converted into steam by the heated powder; the steam escapes through the asphalte, so that fissures appear when the surface begins to wear. When the ingredients are mixed in wrong proportions, the pavement creeps and its surface becomes wavy. Neglect of these matters led to failure in many of the earlier attempts to construct a satisfactory street covering with this material.

491. Spreading the Asphalte Powder.—The heated powder is spread to a depth of about 3 inches upon the concrete foundation, and raked so as to present a layer of regular depth and uniform surface. The powder is then rammed with iron disc-shaped punners, weighing about 10 lbs., heated to prevent the adhesion of the powder. The punning should be performed lightly at first to ensure an equal thickness of the material, and the force of the blows subsequently increased until the whole is solidified. The pavement is then smoothed with suitable curved hot iron tools, and finished with a hand roller weighing about half a ton, the process being repeated so as to compress the asphalte to the required thickness of 2 inches, and until it is quite cool.

A light sprinkling of sand is generally thrown over the finished surface, a few hours after which the pavement will be ready for traffic.

In the case of asphalte pavements laid with bituminous limestone powder, as described above, the ultimate consolidation does not take place till some considerable time after the thoroughfare has been opened to traffic. It is not until then that the actual wear of the pavement commences.

492. Trinidad Asphalte.—This asphalte is generally laid on a Portland cement concrete foundation similar to that for other kinds of carriageway pavements, and upon this a bituminous concrete course may be advantageously introduced, the wearing surface being united to it in one mass, preventing, or at all events minimizing, the forming of a wavy surface and cracking.

In addition to concrete foundations, existing pitched and cobblestone pavements and also macadam roads may be used for carrying the asphaltic wearing surface. This is accomplished by first cleaning out all earth and soft material from the joints; the surface is then brushed and watered to receive a grouting of cement or hydraulic mortar, and to fill up the depressions, and on this the binder course is spread. This method has only been tried to a limited extent in this country, but in the United States it is extensively practised, where Trinidad asphalte as a paving material is almost exclusively preferred.

The manufacture of bitumen (which is found in a crude state in the West Indian Islands and South America, Trinidad 'pitch lake' being the best source and at the same time furnishing the most valuable kind) requires careful manipulation to ensure a satisfactory and durable carriageway pavement. The hard or compact bitumens are the most useful varieties, but they require to be purified or refined in order to free them from foreign matter. Refined bitumen is hard and brittle, and consequently requires the addition of a residuum oil as a flux. The proportion of the flux varies from 10 to 12 lbs. of oil to 100 lbs. of refined bitumen according to the quality of the flux, hardness of the bitumen, the purpose to which and the locality where the asphalte is to be applied. The bitumen is melted and raised to a temperature of 300° Fahr. before the oil, previously heated, is added to the mixture, and it is then agitated by mechanical means or by a blast of air until it has acquired the desired properties.

When in this particular condition it forms the matrix of the asphalte, the aggregate being composed of clean sharp sand and stone or limestone dust. The proportion of these ingredients for carriageway pavements varies, according to the character of the aggregate, amount and nature of the traffic, and the climate of the district where it is to be used.

As the success of this particular kind of pavement depends upon the care and judgment exercised in selecting and combining the materials, and

on the laying of the pavement, skilled labour and special machinery only are employed.

The ingredients, previously heated as described, after being measured (according to the circumstances just mentioned), are thoroughly incorporated in a mixer, after which the composition is ready for use. It is conveyed in specially constructed and equipped carts to the street where the asphalte is to be laid, and there spread with iron rakes to a depth which will give the desired ultimate thickness, varying from 1½ inches to 2 inches when compressed by means of a steam-roller weighing 7 tons, which is equal to a compressive force of 170 lbs. per inch of width.

To obviate creeping, and consequent cracking when laid on a Portland cement concrete foundation, it is necessary to spread a cushion layer of bituminous concrete, or 'binder' as it is termed, between the foundation and the asphalte forming the wearing surface. This binder course is purposely made more plastic or cementitious than the upper or wearing layer of asphalte, so as to combine the whole in a homogeneous mass.

The method of laying Trinidad asphalte on an existing foundation in this country is as follows, the matrix and aggregate of the wearing surface being approximately as under:—

Asphaltic cement, from	12 to 15 per cent.
Sand, from	83 to 70 ,,
Pulverised carbonate of lime, from . . .	5 to 15 ,,
	100 100

In order to make the pavement homogeneous, the proportion of asphaltic cement may be varied according to the quality and character of the sand. The carbonate of lime may be reduced, or entirely omitted, when suitable sand can be obtained.

493. Trinidad asphalte pavement for first-class carriageways is generally laid to a total thickness of 2½ inches, composed of—

Binder, ...	1 inch.
Asphalte surface, ...	1½ ,,
Total, ...	2½ inches.

Binder Course.—The binder course consists of a fine bituminous concrete composed of clean broken stone, slag, or gravel, in pieces not exceeding 1½ inches in their largest dimensions, thoroughly screened, and asphaltic cement made from Trinidad bitumen. The stone, slag, or gravel must be heated by being passed through revolving heaters, and thoroughly mixed by machinery with the asphaltic cement, in the proportion of about 15 gallons of the latter to 1 cubic yard of stone, slag, or gravel. The material thus treated is then conveyed to the work, and spread on the foundation with hot iron rakes, and immediately rammed and compressed with steam

rollers, while the mixture is in a hot and plastic condition, until it has a thickness of 1 inch. The top surface of the binder course should be made exactly parallel with the surface of the pavement when finished.

494. Wearing Surface.—Upon the binder course the wearing surface or asphalte pavement is laid, the composition of which varies in the proportions stated at p. 352, the density of the pavement being determined as that best adapted to the climate and traffic.

The sand and asphaltic cement are heated separately to about 300° Fahr. The pulverised carbonate of lime, while cold, is mixed with the hot sand in the requisite quantities, and is then incorporated with the asphaltic cement at the required temperature and in the proper proportions, in a suitable apparatus which will effect a perfect mixture.

The pavement mixture, prepared in the manner described, is then laid upon the binder course in one coat; it should be brought to the ground in carts or wagons, at a temperature of about 250° Fahr., and carefully spread by means of hot iron rakes. This must be carried out in such a manner as to give a uniform and regular surface, and to such a depth that, after having received its ultimate compression, it will have a thickness of 1½ inches. The surface is first compressed by hand rollers, after which a small quantity of cement is swept over it, and then thoroughly compressed by means of a steam roller, the operation being continued so long as the roller makes an impression on the surface. One cubic yard of prepared material weighs about 1¼ tons, and the area which it will cover when spread to different thicknesses is as follows:—

Pavement	2½	inches	thick,	about	12 square yards.
,,	2	,,	,,	18	,,
,,	1½	,,	,,	27	,,

Fig. 126 shows a cross-section of asphaltic pavements of bituminous limestone and Trinidad asphalte.

495. Many combinations of this class of pavement have been introduced and applied in this country with varying success, the source of supply where the necessary constituents are obtained sometimes giving the name, apparently new, to the pavement, which is, however, in reality only a different composition in regard to the quality of the bitumen, the nature of the flux used, or the other essentials which go to make a successful artificial, but at the same time compressed asphaltic pavement.

496. Bitumen and Crushed Granite Pavement.—Bitumen and crushed granite mixed together as a paving material has been experimented upon in the United States, and lately in Paris, where it has been laid in the following manner:—The first layer of asphalte, a thin coat, is spread on the beton foundation, followed by a layer of about ¾ inch crushed granite, which is floated with a grouting of liquid asphalte, then finished with a coating of fine crushed granite and thoroughly well rolled.

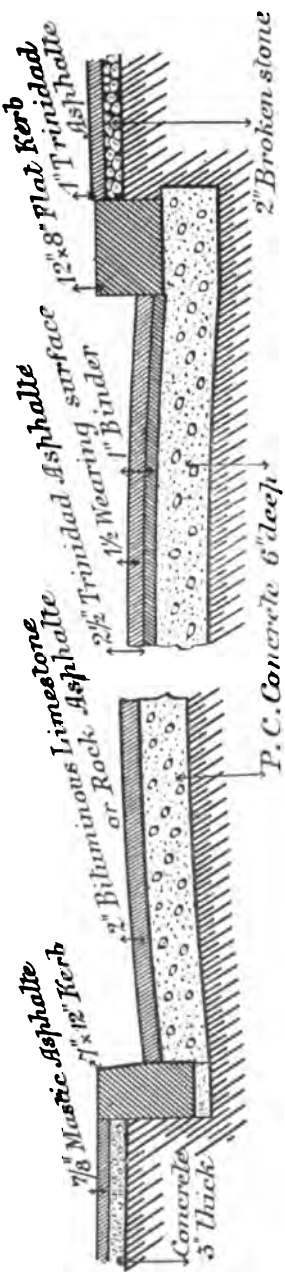


Fig. 126.—Cross-section of asphalte pavements.

This pavement is being used extensively, and is stated to be giving satisfactory results.

497. An asphaltic pavement recently introduced from the United States was laid in Glasgow about two years ago. It is known as 'Alcatraz,' which, in America, is a trade name for the 'flux' employed in many of the compositions there used, and which are also called asphalte.

This new description of paving material was laid in Buchanan and Castle Streets, Glasgow, in September and October 1897, to a thickness of 3 inches by skilled workmen, and guaranteed by the contracting company who undertook to maintain the pavement for four years free of cost to the Corporation. Singularly enough this pavement, which was laid on a thoroughfare subject to heavy traffic, did not survive twelve months, owing probably to the composition of the ingredients; it was lifted and re-laid a second time, but again showed signs of giving way during the winter months. On account of this failure the American company lifted the whole of the pavement laid by them, and re-laid it a third time in July 1899, the composition of the ingredients being slightly altered, and it is now stated to be wearing well. It is a matter for conjecture whether this pavement, as originally laid, was such as to stand the climate of Glasgow, or whether some accidental circumstance had intervened to partially destroy the pavement, which to all appearance was well constructed. The cost of this paving in Glasgow averaged about 7s. 6d. per square yard.

498. Asphalte pavements for carriageways are eminently suited for cities and towns having comparatively level thoroughfares. Among other advantages which these pavements possess, the following may be mentioned. They are jointless, have a

smooth even surface, are absolutely impervious to moisture, and dry quickly after a fall of rain; they are comparatively noiseless, and easy of traction, consequently they are pleasant to drive over, owing to the absence of vibration and concussion. They are very durable, quickly laid and easily repaired, a matter of considerable importance in thoroughfares where continuous wheel traffic exists, and this greatly lessens the inconvenience of long delays during renewals, and corresponding inconvenience to business people and shopkeepers. They neither absorb nor radiate heat, and having a smooth surface, they can be quickly and easily cleansed, and are, therefore, perfect sanitary pavements; they can be kept scrupulously clean by washing, which no other kind of street pavement is capable of in so effective a manner.

499. Asphaltes thus comply with almost every requirement necessary for a first class carriageway pavement, except in one great particular, namely, slipperiness. Especially is this so in the case of compressed rock asphalte, the limestone of which becomes hard, smooth, and slippery under traffic.

The slippery state of these pavements is worse in certain conditions of the atmosphere such as during the prevalence of fogs, and after a light shower of rain, when the dirt which may be, and indeed generally is, lying on the surface, is converted into a greasy film, and horses retain their foothold with difficulty. This mainly affects horses drawing heavy loads, especially when stopping or starting, and also fast travelling traffic.

A continuous or heavy rainfall cleanses the surface to a certain extent, and in this thoroughly wet and at the same time clean condition, it is then safe to travel over. The application of sand sprinkled over the surface renders this kind of pavement less slippery, but this advantage is gained at the expense of the asphalte covering, the surface of which is cut into by the sand, and so worn and defaced. This remedy is, moreover, only a temporary one, as it has to be frequently repeated during adverse conditions of weather, and ultimately it has to be swept off in the form of mud.

500. As these pavements are constructed, and in most instances maintained, by contractors, it is the practice of the 'Asphalte Paving Companies' to charge a certain price per square yard for laying according to the thickness required, and also to maintain the surface in good repair at a fixed price per square yard annually, for a definite number of years.

This arrangement, therefore, does not admit of a direct comparison with other descriptions of pavement similarly situated, where constructed and maintained by the authorities' own staff; the cost of the annual maintenance, no doubt, is given, but as this will in most instances be a fairly remunerative figure, the actual cost for repairs, on different pavements, can only be arrived at approximately.

501. It is difficult to ascertain the actual life of asphalte pavements under traffic, for the reason that repairs are immediately carried out when

required, probably in three or four years after being laid; consequently, the whole surface in the course of time is in reality relaid or renewed.

The Val de Travers compressed rock asphalte, laid in the Poultry and Cheapside, London, in the latter part of 1870, was in use for eighteen years before being lifted and renewed. This asphalte pavement, which was laid to a thickness of 2¼ inches, cost 16s. 3d. per square yard, and 1s. 9d. for the concrete foundation 9 inches thick, or an inclusive cost of 18s. per square yard. The average width of the carriageway between the kerbs is 22 feet in the former, and 30 feet in the latter thoroughfare, while the wheel traffic (1872–73) is stated to have been 363 and 298 vehicles respectively per foot of width in twelve hours, no weights however being given.

502. The first cost and expenditure on maintenance of the two streets mentioned, along with some others, are given in the following table, the pavements having been repaired by contract for a period of seventeen years.*

The wear, or loss of thickness, was equal to ·35 inch next the kerb, and ·22 inch over the general surface annually in Cheapside and the Poultry, while in some of the other thoroughfares it amounted on an average to ·16 inch, and in Moorgate Street to ·1 inch per annum next the kerb.

Another table, LV., is also given, which shows the cost of the different items already enumerated, but is of more recent date.

503. The approximate cost of asphalte rock pavements in the city of London at the present time, exclusive of foundations, is as follows:

	1½ inches thick.	2 inches thick per square yard.
Val de Travers asphalte,	9s. 9d.	12s. 6d. ,,
Limmer ,,	9s. 6d.	12s. ,,

Like those already detailed the cost for annual maintenance varies according to the locality and amount of traffic passing along the thoroughfare, but is generally repaired free of cost for the first two or three years.

Trinidad asphalte, exclusive of foundations, varies from 7s. 6d. to 10s. 6d. per square yard, according to the thickness of the binder course and wearing surface, quantity required, and also the locality and distance from the works.

These are the prices for work carried out by the Trinidad Lake Asphalte Paving Company, and their arrangement for repairs, after from three to five years' free maintenance, is a charge of from 3d. to 6d. per square yard annually, according to the volume of the traffic and other circumstances.

* Compiled from "Roads and Streets" (Colonel Haywood's report), by Law & Clark, *Weale's Series*, No. 197.

TABLE LIV.

The cost of the concrete foundations in each case was 1*s.* 9*d. per square yard. All these pavements were laid between December* 1870 *and April* 1871.

LOCALITY. Val de Travers (compressed).	Depth of concrete foundation.	Thickness of asphalte.	Period of maintenance.	First cost per square yard exclusive of foundations.	Contract cost for maintenance per square yard.	Total cost per square yard.	
						Total.	Per year.
Cheapside, . . .	9 inches.	2½ inches.	17 years.	16s. 3d.	2 years free. 15 ,, at 1s. 6d.—22s. 6d.	38s. 9d.	2s. 3½d.
Poultry, . . .	9 ,,	2¼ ,,	17 ,,	16s. 3d.	2 years free. 15 ,, at 1s. 6d.—22s. 6d.	38s. 9d.	2s. 3½d.
Old Broad Street, . .	6 ,,	2 ,,	17 ,,	14s. 3d.	2 years free. 15 ,, at 9d.—11s. 3d.	25s. 6d.	1s. 6d.
Gracechurch Street, .	9 ,,	2⅛ ,.	17 ,.	15s. 3d.	2 years free. 15 ,, at 1s.—15s.	30s. 3d.	1s. 9½d.
Finsbury Pavement, .	6 ,,	2 ,,	17 ,,	14s. 3d.	2 years free. 15 ,, at 9d.—11s. 3d.	25s. 6d.	1s. 6d.
Moorgate Street, . .	6 ,.	2 ,,	17 ,,	14s. 3d.	2 years free. 15 ,, at 9d.—11s. 3d.	25s. 6d.	1s. 6d.
Queen Street, . .	9 ,,	2⅛ ,,	17 ,,	14s. 3d.	2 years free. 15 ,, at 9d.—11s. 3d.	25s. 6d.	1s. 6d.

TABLE LV.

Showing cost per annum of certain asphalte pavements in London.

SITUATION.	Description of asphalte.	Years to be maintained by contractors.	First cost per square yard.	Agreed cost of maintenance per square yard for the contract term.	Total cost of pavements during contract term per square yard.	Average cost per square yard per annum.
			s. d.		£ *s. d.*	*s. d.*
New Oxford Street, . .	Val de Travers compressed,	17	12 6	2 years free. 15 ,, at 10d.—12s. 6d.	1 5 0	1 $5\frac{1}{2}$
Minories, ...	Ditto, ...	17	12 6	2 years free. 15 ,, at 9d.—11s. 3d.	1 3 9	1 $4\frac{3}{4}$
Great Russell Street, .	Ditto, ...	17	12 6	2 years free. 15 ,, at 6d.—7s. 6d.	1 0 0	1 $2\frac{1}{8}$
Tottenham Court Road, .	French asphalte compressed,	17	13 6	2 years free. 15 ,, at 10d.—12s. 6d.	1 6 0	1 $6\frac{1}{8}$
Coleman Street, . .	Ditto, ...	17	12 0	2 years free. 15 ,, at 3d.—3s. 9d.	0 15 9	0 $11\frac{1}{8}$
Southampton Row, . .	Ditto, ...	17	12 6	2 years free. 15 ,, at 6d.—7s. 6d.	1 0 0	1 $2\frac{1}{8}$
Red Cross Street, . .	Limmer compressed, .	17	12 0	2 years free. 15 ,, at 9d.—11s. 3d.	1 3 3	1 $4\frac{1}{2}$
Golden Lane, ...	Ditto, ...	17	12 0	2 years free. 15 ,, at 8d.—10s.	1 2 0	1 $3\frac{1}{2}$

CHAPTER XII.

BRICK PAVEMENTS, TAR MACADAM, AND MISCELLANEOUS MATERIALS USED FOR CARRIAGEWAYS—CONCLUSIONS.

504. Brick Pavements for carriageways are extensively used in the United States, where they were first adopted in 1872; many of the streets in the principal towns in Holland are paved with this material, particularly in Amsterdam and Rotterdam, where bricks are stated to have been employed for paving purposes for over 150 years. Bricks have not hitherto been used for paving to any great extent in this country, although there are towns with a medium traffic where it has been laid as a pavement; they are, however, much used in forming street crossings.

505. In Liverpool, 'Tees scoriæ' bricks from Middlesbrough were laid as a trial in 1881; they were not, however, very successful, wearing unevenly and being extremely slippery. The unequal wearing was probably owing to the manner in which they were manufactured, as, on examination, many of the bricks were found to have large holes in them, where the materials had not fused together.

A section of the thoroughfare in Upper Street, opposite Islington Green, where the traffic is very heavy, was recently paved with bricks experimentally; it has not, however, proved successful, but further trials are being made in London on streets having less traffic than this thoroughfare.

506. The suitability of bricks for carriageway pavements depends on the quality of the clay from which they are made, the method adopted in manufacturing and burning them, uniformity of shape and size, and the extent to which they will conform to the tests for absorption, crushing strength, and abrasion, while in addition, the specific gravity test, varying from 2·00 to 2·30, is at times adopted.

The characteristics which brick suitable for paving purposes should possess may be stated as follows:—

(1) It should not absorb more than $3\frac{1}{2}$ per cent. of moisture in twenty-four hours, nor be acted upon by acids.

(2) It should be rough to the touch, affording a good foothold, and not liable to become polished.

(3) It should be hard, but not brittle, give a clear ringing sound when struck, and not liable to scale or to chip on the edges.

(4) When broken it should show a compact, uniform, and close-grained structure free from air-holes and small stones.

The composition of clay varies considerably, but most bricks are made from a hydrated silicate of alumina in combination more or less with other substances, such as magnesia, iron, lime, and potash. Alumina gives elasticity, and renders the material tough and binding; magnesia in small quantities renders the clay fusible; iron is advantageous, tends to make the brick more homogeneous, and aids in producing vitrification.

Lime in excess is injurious, and although infusible, is changed into caustic lime at high temperatures, and when exposed to the action of the weather absorbs moisture, and causes disintegration. The alkalies, varying from 1 to 3 per cent., act as a flux in chemical combination with the silica and alumina.

Clay, to make satisfactory paving bricks, must be rich in silica, free from lime, and able to withstand without fusing a red heat for a sufficient length of time to render the bricks hard, homogeneous, and impervious to water.

507. The methods practised in preparing the clay previous to being manufactured into paving bricks vary considerably, but the essential points may be stated as follows, namely—(1) preparing and grinding the clay, (2) tempering, (3) moulding, (4) drying, (5) burning, which will be briefly described.

(1) The clay is prepared by removing all stones or other foreign impurities, and then grinding it; different methods are used, but the finer the clay is ground the more homogeneous will the brick be.

(2) Tempering the clay is performed in a variety of ways, but generally by machinery in the form of pug-mills.

(3) The clay is then placed in moulds and pressed by hand, or by machinery, the object being to compress the utmost amount of clay into the moulds.

(4) The bricks, after being moulded, are slowly dried either in covered sheds open to the air, or in chambers heated for the purpose.

(5) The bricks when sufficiently dried are then piled in kilns and burned, either on the up-draught or the down-draught system; the firing should be conducted with great care, as the perfection of the bricks depends largely on the skill with which this operation is carried out. It is an important matter when the burning is completed—that is, just short of fusion—to allow the heat in the kiln to be reduced gradually. This process of annealing produces a thoroughly compact, tough, and hard brick. The time required for burning may extend to six or more days.

For all practical purposes, although all the tests mentioned are sometimes

carried out, the suitability of bricks for paving purposes may be judged by their capacity for absorption and abrasion.

508. Absorption.—This test, which represents the probable effect of atmospheric action, is of great importance; it is one of the factors which determine the life of a brick pavement. The alternation of wet and dry weather to which all pavements are subject at times, and also the freezing and thawing tend to disintegrate bricks, so that the less absorbent they are, the more durable and sanitary they will be. American specifications generally stipulate that paving bricks must not absorb more than $1\frac{1}{2}$ to $3\frac{1}{2}$ per cent. of moisture in twenty-four hours, although the time required for this test is at times extended to forty-eight and seventy-two hours.

509. Abrasion.—This test for paving bricks is also of importance, and is carried out in a somewhat similar manner as in testing road metalling. The pounding produced by horses' feet on most pavements and especially on this class, causes the greatest amount of wear, so that the material which can withstand this treatment will, in all probability, be the most suitable and give the longest service as a pavement.

There are no standard conditions by which different bricks can be compared, the 'rattle' or 'tumbler' test being carried out with the bricks placed in it alone or with iron castings or other material introduced. The construction of the testing machine, the number of revolutions per minute, the duration of the test, and the percentage of loss are all matters which have a direct bearing on the subject.

510. So far as the resistance to crushing of bricks is concerned, it seems remarkable that some specimens should possess a greater crushing strength than most kinds of granite, although they are not so tough. Staffordshire blue bricks, tested by Kirkcaldy, gave the crushing resistance at from 15,000 to 18,000 lbs. per square inch, while the strength of granite similarly tested, varied from 12,000 to 18,000 lbs. per square inch.

In the United States, where particular attention is paid to the manufacture and burning of bricks for paving purposes, recent tests at Watertown Arsenal showed that 22,000 lbs. per square inch was attained. In some cases the crushing resistance has reached the abnormal figure of 30,000 lbs. per square inch, but 7150 lbs. per square inch appears to be the average in America. The tests are carried out there on a very extensive scale, testing laboratories having been established, equipped with suitable apparatus for this purpose.

As the suitability of bricks as a paving material depends on the nature of the clay from which they are manufactured, careful analysis and tests are absolutely necessary where this pavement is laid to any great extent.

Brick paving has been in use in America for nearly thirty years, but more particularly during the last seventeen years has it extended, especially

in districts where suitable clay is easily obtained, and where other pavements are prohibited on account of cost alone.

511. Size of Bricks.—The standard size of building brick in this country is 9 inches × 4½ inches by 3 inches, and it is considered that this would also form a convenient size for paving purposes.

In the United States the sizes vary considerably, but the dimensions of brick mostly used are 9 inches × 4 inches by 3 inches. They are formed with square edges and rounded nosings, while many are made with rounded tops. The square edge makes the best joint, is less noisy, and more readily cleansed, although the arrisses become chipped by the action of the horses' feet.

512. Foundations.—Many of the brick pavements in the United States were simply laid on the natural ground, previously rolled; in other instances, slag, gravel, and ordinary macadam have been used and steam-rolled before laying the brick pavement.

The best work is now, however, being carried out by forming a concrete foundation similar to that used for first-class pavements in this country, and no doubt the success of the paving will be greatly enhanced, and the life or service of the bricks extended, if laid on concrete.

513. Laying.—The bricks are laid on a cushion of sand, as in the case of a pitched pavement, at one time spread to a depth of 3½ inches, but now generally from 1 inch to 2 inches in thickness. The bricks are laid on edge close up to the kerbs without any channel courses, at right angles to the centre line of the thoroughfare, or at an angle of 60°, which is preferred in some towns. The bricks are for the most part laid with as close a joint as possible, but in some cases with a ⅛-inch space to allow for grouting. The irregular shape of the bricks generally permits of a sufficiently wide joint for this purpose. Closers are specially made to avoid cutting the ordinary bricks, and vary from ¼ to ¾ lengths. The paving is then rammed or rolled with horse-rollers drawn by men, or by light steam-rollers; any defective bricks being replaced before filling the joints.

514. Grouting.—This is effected with clean river sand, cement, or pitch. In the case of the two latter materials, the joints are filled by means of an iron funnel-shaped tool, having a small hole at the bottom, the flow of the grout being regulated by a plug valve.

The surface is finished by covering the pavement with course sand from ½ inch to 1 inch in thickness, which is allowed to remain for ten or twelve days, the traffic passing over the pavement meanwhile, and is then swept off.

Specifications for brick pavements differ widely in their requirements, and, as already mentioned, no standard for testing the quality, or the method of construction, has been arrived at.

515. The following, however, will give a general idea of the manner in which this class of pavement is carried out in Indianopolis, U.S.A.

New specification for brick paving as adopted by the Indianopolis Board of Public Works.*

1. Upon the foundation of concrete or broken stone, as specified, will be laid a bed of fine sharp sand, free from loam and vegetable matter, and which will pass through a $\frac{3}{8}$-inch mesh.

The layer shall be 2 inches in thickness when compacted to serve as a bed for bricks, which will be laid directly upon and imbedded in it, with close end and side joints.

2. The bricks or blocks must be specially hard burned for street paving, free from flaws, cracks, or breaks, and equal in all respects to the samples for the pavement tendered upon to be filed in the office of the board. The dimensions shall not be less than $2\frac{1}{4}$ inches in thickness, by 4 inches in depth, and 8 inches in length. The variations in size of bricks furnished must not be more than $\frac{1}{4}$ inch in thickness or depth. If the bricks furnished are found to vary more than the specified amount, they shall be sorted and properly laid with reference to sizes, as directed by the engineer.

3. The kind and size of brick shall be specified in the tender and shown by the samples submitted, and the contractor shall also, if required, furnish samples of materials used in their manufacture and analyses of the same, and a statement showing the kinds and proportions of material used in making the brick, and the manner of making and burning the same. The brick shall be subject to test at any time, and the contractor must furnish the brick selected by the engineer for test without additional compensation.

4. All bricks shall be subject to thorough inspection by the engineer and his agents, both before and after laying, and all rejected material shall be removed from the street immediately, and deficiencies made good by the contractor, and he shall at all times provide at his own expense a sufficient number of men to assist the engineer and his inspectors in the proper inspection and culling of the bricks.

5. Upon the cushion, when prepared as above specified, the paving bricks are to be laid in the following manner.

The pavement is to be constructed with a single layer of bricks laid on edge, end to end, in right angle or diagonal courses across the street, except at street intersections, where the courses are to be placed at such angles as the engineer shall direct.

The bricks are to be set in straight courses, with the body of the bricks close together, sides and ends touching, and breaking joints at least 2 inches with the bricks in adjoining courses. The contractor may be required to lay every tenth course to a line. They are to be set perpendicular to the grade of the street, and to a height of $\frac{1}{4}$ inch to $\frac{3}{4}$ inch, or such other height as the engineer may direct, above the true grade and crown of the street

* Extracted from paper on "Brick Paving for Carriageways," by John T. Eayrs, M.I.C.E., F.S.I., *Proc. Assoc. of Municipal and County Engineers*, vol. xxiii.

when finished, to provide for settlement in ramming and rolling. Nothing but whole brick shall be used, except in starting courses or in making a closure at kerbs, catch basins, rails, and street structures, when not less than half bricks may be used in breaking joints, which shall be made tight and close at the ends.

Great care shall be taken in breaking and trimming the bricks for the purpose, so as not to check or fracture the part to be used; all joints shall be broken or cut at right angles to top and sides of bricks. The breaking and trimming must be done by experienced men working with proper tools.

6. The paving, when laid as specified, and before the filling of the joints and top dressing is put on, shall be thoroughly rolled three or more times lengthwise of the street, with a roller weighing not less than 5 tons. All parts of the pavement which cannot, in the opinion of the engineer, be properly rolled, shall be thoroughly rammed three times or more in such manner as the engineer shall direct.

7. All soft, cracked, or defective brick found in the pavement at any time before the pavement is accepted, whether developed by rolling, ramming, or otherwise, shall be removed by the contractor and replaced at his expense.

8. The contractor shall remove all rubbish and thoroughly sweep the street for inspection of grade, surface, and material before joint filling is put on.

9. The joints shall then be filled as nearly as possible from bottom to top with a paving cement or grout, as specified in the tender and contract, and according to a formula for composition and consistency of same, approved by the Board of Public Works and the engineer. Sand may be used as a filler in alleys when specifically stated in the specifications, to be applied as directed by the engineer.

10. When grout is used, it must be equal or superior to a grout composed of one part of Portland cement by measure, and one-and-a-half parts of fine sand which will pass through a $\frac{8}{16}$ inch mesh. It shall be of such a consistency as to run readily into the joints, and shall be swept in rapidly. The pavement shall be gone over a sufficient number of times to fill every joint. When the foundation is of broken stone, the engineer may require the grout to be put on in two coats, the first coat to be of such proportions as he may direct.

11. When paving cement is used, it must approach as nearly as possible to the condition of being pliable, not brittle, in cold weather, and so solid in hot weather that there will be no tendency to run out of the joints. It shall be equal or superior in quality to a cement composed of 10 per cent. of refined Trinidad asphalte, mixed with 90 per cent. coal tar paving cement, distilled at a temperature not less than 600° Fahr. The temperature shown on the gauge attached to the cement tank shall show not less than 300° Fahr. while the cement is being applied, and shall show such higher degree as the engineer may direct, if considered necessary by him on account of

weather or character of materials used, to render the cement fluid enough to run into the joints properly.

The paving cement shall not be used unless the bricks are thoroughly dry. The cement shall be carefully poured from a vessel having a small spout, so that it will run into the joints directly. This will be insisted on, especially in cool weather.

Any excess of cement on the surface shall be broomed off so as to leave as little as possible thereon. Great care must be taken not to disfigure the kerb, walks, or lawns with materials, and any damage on this account must be repaired by the contractor. Extra care and material must be taken at the gutters and around catch basins or other structures in filling all joints in both paving and kerbing to effectually prevent the leakage of water into the sub-roadway. All joints shall be completely filled to the top before the top dressing is put on.

12. The surface of the pavement, when completed as above, shall be covered with a ½-inch top dressing of clean coarse sand of an approved quality. The sand shall be removed by the contractor in two weeks after completion of the pavement or on notification from the engineer.

13. The Board of Public Works reserves the right to change the kind of brick or filling to be used in the pavement, even after the contract has been let; this, in case it is found necessary to do so by the failure of the contractors to furnish the materials tendered upon and mentioned in the contract to be used.

516. Advantages and Defects of Brick Pavements.—The advantages of a brick pavement are stated to be ease of traction and fairly good foothold for horses; it is easily repaired and cleansed, consequently it is sanitary; and it is durable under moderate traffic. The defects of brick pavement arise principally from the lack of uniformity in shape and quality, which necessitates the making of a wide joint in most cases, while the soft or more porous bricks are liable to disintegrate under the action of traffic or the effects of frost.

517. Life of Brick Pavements.—In America, where the experience of this description of pavement, laid on concrete foundations, has extended to a period of about seventeen years, the life time is stated to be from fifteen to twenty years under ordinary conditions. In many instances, where the paving has been down for ten or twelve years, it is reported to be in good condition and but little worn.

The durability of course depends greatly on the nature and amount of wheel and hoof traffic, and also the climatic conditions, which latter, it must be remembered, are more severe there than in this country.

518. Cost.—The cost of constructing a brick pavement in the United States varied in 1890 from 5s. to 9s. per square yard; the latter was on a foundation of concrete.

It is reasonable to suppose that brick paving could be carried out in this country, when the bricks can be obtained within a moderate distance of the locality where they are to be laid, for 6s. 4d. per square yard, or 8s. 10d. per square yard, including a concrete foundation 6 inches deep.

519. M'Dougall's Patent 'Combination Sett Pavement.'—A great many street crossings in provincial towns are laid with this patent pavement, which is stated to wear well, and give an excellent foothold for horses. It consists of a highly vitrified blue paving brick, 10 inches × 4½ inches by 5 inches, containing recesses on the top or wearing surface, into which square plugs of creosoted wood 1 inch square and 2 inches long are driven, so as to project $\frac{1}{16}$ inch above the surface of the brick. It is laid on a concrete foundation, with close joints and grouted with a bituminous mixture; it is claimed to be a durable and non-absorbent pavement, wears evenly, and is not slippery, while it is readily handled and laid, and cheap in first cost.

520. Cork Pavement.—This paving material, which is of an elastic nature, is composed of cork ground very small mixed with bitumen and fibre. The blocks are made in moulds, and measure 9 inches × 4½ inches by 2 inches in depth, and are subjected to a hydraulic pressure of 600 lbs.

The foundations are prepared in the usual way by spreading Portland cement concrete 6 to 9 inches deep, and finishing to a proper contour, then floating the surface with cement in order to form a thoroughly smooth surface. The foundation, when thoroughly dry and set hard, is coated over with a thin layer of hot tar and tallow mixture, in the proportion of 4 oz. of tallow to one gallon of tar. The general practice is, however, to apply a thin coating of mineral tar spread with a brush. This is allowed to set or cool previous to commencing the laying of the blocks.

The cork blocks are then dipped in a hot jointing mixture composed principally of asphalte, at such an angle that the entire bottom is covered, and nearly the whole of the way up one side and end. This is readily done by using a slater's hammer, or other similar sharp pointed tool; the blocks are then quickly and firmly placed in position, keeping the joints as thin as possible, but full of bitumen, and the surface of the block at its proper level.

It is claimed for this pavement that it is non-absorbent, non-slippery, resilient, and practically noiseless. When these blocks are laid in position they form a solid and thoroughly sanitary pavement.

It is giving great satisfaction where it has been tried, and is slowly creeping into favour. This class of pavement has been laid for a few of the Vestries and the County Council of London. It has also been laid in Bournemouth, Nottingham, Hanley, Windsor, and York. Many of the railway companies use this description of paving material.

The cost of this pavement, including laying and jointing material, on a

newly prepared or existing foundation is 10s. 6d. per square yard in London, and varies from this price to 15s. per square yard in the provinces.

521. Sanitary Block Pavement.—These blocks are composed of granite chippings, or other suitable stone partly pulverised and then heated to a high temperature, mixed with a certain proportion of Trinidad asphalte, and finally subjected in this heated state to an immense pressure, and moulded into a solid homogeneous block, measuring 12 inches × 4 inches × 4 inches.

This pavement is laid in the same way as a pitched carriageway, on a concrete foundation and cushion bed of sand. The blocks are uniform in shape, and are laid close together; the joints soon become closed by compression under traffic, but they are generally filled with cement grout. It is claimed for this pavement that it is non-absorbent, does not polish or become slippery, and can be used with safety on gradients up to 1 in 25. It is comparatively smooth, is easy of traction, affords a sure foothold for horses, is noiseless, is not affected by heat or cold, and can be easily cleansed.

This pavement has been in use in Philadelphia, Washington, and other American towns for over fifteen years; it was laid in Carlos Place, Grosvenor Square, and at the Cumberland Gate entrance to Hyde Park, London, two years ago, and is giving every satisfaction, especially in regard to foothold for horses.

Sanitary block pavement can be laid at a cost of 15s. per square yard in London and towns on the west coast.

522. Tar Macadam.—This pavement is very suitable for thoroughfares which are comparatively level, in suburban districts and towns with medium traffic, and makes an excellent substitute for ordinary macadam.

It is of very old standing, and, although not extensively used in the past, is now being introduced into districts where its principal ingredients are readily obtainable. It is less expensive to maintain than a steam-rolled macadam roadway; the initial cost, however, is much greater. Tar macadam forms a smooth pavement, is practically noiseless, non-absorbent, and easily cleansed.

Tar macadam paving has been executed by different methods with varying success, and in many instances failure, depending on the system adopted, the quality of the materials employed in the different localities where used, and the nature of the weather when the paving operations were carried out. The tar, which acts as a water-tight cement on the stone forming the aggregate and protects it from weathering, is of variable quality.

523. It is occasionally used in a natural state after having been stored for several months to allow the volatile oils and water to escape or come to the surface. When used under these circumstances for paving purposes, it should be drawn from the lower end of a covered tank of some depth. The same result is attained during the boiling operations; the lighter the tar the longer must it boil, so that all light oils and water may be driven

off. It is now, however, generally used in the refined or distilled state, which gives the best results.

524. The stones which form the bulk of the mixture may consist of flints, granite, whinstone, or gravel; but for really successful work Kentish ragstone or mountain limestone alone should be employed, as a more reliable and durable pavement will be the result. The stones should be fairly tough and sufficiently permeable to admit of the tar being partially absorbed, which is a necessary quality for making tar macadam. The preparation of the aggregate, previously broken to the requisite gauge, so as to remove moisture and to make the tar adhere more readily to the stone, is performed in various ways.

525. The old method of accomplishing this is to make a stack of stone and coke of rectangular shape, or in the form of a cone, and burning the pile in the open. The stones, varying in size up to a 2-inch gauge, are laid to a depth of about 12 inches, and on this is spread a layer of coke and breeze 3 to 4 inches thick, along with a few pieces of wood to assist the fire; the stack is carried to a height of about 5 feet and then kindled. The fire penetrates the mass, the process of burning occupying from four to ten days, according to the size of the stack. By this process of drying the stone, however, a considerable amount of disintegration takes place, or, in other words, the material is calcined, which, besides reducing a considerable quantity of it to sand, affects the ultimate strength of the pavement. It takes a long time to accomplish, while ashes and other foreign matter are incorporated with the stone.

526. The usual method, and one which obviates the defects mentioned, is carried out by means of a drying stove. The material is placed on a hot hearth, the temperature of which can be raised to a sufficient degree in order to expel all moisture from the stone, and at the same time the heat can be so regulated that the aggregate will absorb as much tar as possible. The hot tar is then added to the heated stone and the mixture turned over with hot shovels, and thoroughly incorporated, until all parts of the stone are well coated. The material, before being so treated, is screened so as to graduate the different sizes of stone to form the paving. This is done by storing all the stones from 1 inch to 2 inches gauge to form the bottom layer, the $\frac{1}{2}$ inch to 1 inch sizes for the intermediate coat, and $\frac{1}{4}$ inch to $\frac{1}{2}$ inch material for the top dressing.

The tar, previous to being conveyed to the heap of stones, is boiled in suitable cylinders or coppers and maintained at the boiling point for three or four hours, according to the quality of the tar; a small percentage of pitch being sometimes added.

527. The quantity of tar cement employed varies according to the quality of the stone used, and whether the mixture is to be laid immediately after being prepared, or stored, in which case it should be placed

under cover and there allowed to mature. In the latter case less tar is made use of, but when about to be laid it is again heated with some additional tar.

During the summer time, and when the mixture is to be laid as soon as convenient after mixing, the following proportions are found satisfactory:—

	Gallons per cubic yard.
For the 1-inch to 2-inch material,*	8
,, intermediate layer ½- to 1-inch gauge material, . . .	10
,, top dressing or ¼-inch to ½-inch, ...	12

528. The method of laying tar-macadam depends on circumstances; the foundation is generally carried out as for an ordinary macadamized road, the depth being about 4 inches in thickness. The material may consist of dry hard stones, furnace clinker, or broken bricks regulated so as to give the desired contour after being steam-rolled, and when this is laid, the whole surface is then floated or flushed with well-boiled tar or Portland cement grout. This method of carrying out the work gives the best results, and admits of the tar-macadam covering being reduced in thickness, which will, of course, promote economy in construction. In many cases, however, where the existing coat of metalling is sufficient and the level of the surface permits of the tar-macadam being laid directly upon it, after being properly formed, it is considered to be a satisfactory foundation by many surveyors.

In the former case a total depth of 4 inches of tarred composition will, after compression, be sufficient; the bottom or coarse layer being spread 4 inches thick, the intermediate layer about ¾ inch, and the top dressing just sufficiently thick to fill all interstices. In the latter instance 5 inches of compressed total thickness is generally sufficient, 4 inches being laid for the lower coat, 1½ inch for the intermediate, and ¾ inch for the top dressing.

In either case each layer is steam-rolled separately, the surface being finished with ¼-inch granite or limestone screenings spread over the surface. The weight of the roller employed may vary from 10 to 15 tons, and the rolling process is continued until the consolidation of the composition is such that no movement or creeping takes place. The pavement is finally finished by sweeping or dusting limestone powder over the surface.

During the operations of forming this pavement and for sometime thereafter, traffic should not be allowed to pass over the thoroughfare until the pavement is properly finished.

Tar-macadam for carriageways should be laid in a fresh condition by experienced men under careful supervision, and then only in dry weather, as upon these conditions depend the success and ultimate life of the pavement.

* This is the composition which was used in Canterbury by A. H. Campbell, A.M.I.C.E., late City Surveyor, now city Engineer and Surveyor, East Ham, *Proc. Assoc. of Municipal and County Engineers*, vol. xxiv.

The durability of tar-macadam for carriageways depends, of course, on the amount and nature of the traffic, but is estimated at periods varying from three to ten years, although cases are recorded where it has been in use for twenty and thirty years; this probably refers to roadways subject to light traffic only.

529. The cost of construction likewise varies according to the price of the materials in different localities; this may be stated at from 2s. to 3s. per square yard, and when foundations are included at from 4s. to 6s. per square yard. The annual expenditure for repairs cannot be given with any degree of certainty, but it is stated to average from 4d. to 9d. per square yard.

The following particulars in regard to the cost of preparing a tarred-macadam road paving is given by Mr. A. H. Campbell, late City Surveyor of Canterbury.

"The stack of stone operated on for test contained 45 cubic yards; and the actual cost in preparing that quantity is:—

TABLE LVI.

Debit.

	£	s.	d.
45 cubic yards pit gravel, at 3s. 6d.,	7	17	6
79 gallons tar, and cartage, at 2½d. per gallon,	0	16	5½
284 lbs. of pitch, at 46s. 8d. per ton,	0	4	10½
84 bushels of coke, at 9s. 4d. per chaldron,	1	1	9½
80 ,, breeze, ,, ,,	0	8	0
Wages in preparing and mixing stone and tar,	7	18	7
	£18	7	2½

Credit.

Actual product from the foregoing:—
40 cubic yards of mixture costing £18, 7s. 2½d., equal to 9s. 2d. per cubic yard.
This composition, as above described, laid 4 to 4½ inches thick, finished in compressed condition, will work out at fully 1s. 6d. per super. yard for the mixture alone.

	s.	d.	
To this,	1	6	per super yard
add these items (estimated):—			
1. Stripping road 8 inches thick,	0	9	,, ,,
2. Broken brick ballasting,	0	10	,, ,,
3. Applying the tarred material in three layers and finishing off,	0	9	,, ,,
4. Rolling road,	0	3	,, ,,
5. Add contingencies 10 per cent.,	0	5	,, ,,
Total,	4	6	,, ,,

530. In England this class of road paving has been extensively used in the following towns: Derby, Leicester, Cheltenham, Southport, Nottingham, Canterbury, Harrogate, Norwich, and Croydon.

Tar-macadam has not hitherto been used to any great extent in Scotland, although a few subsidiary streets in Glasgow have been recently laid with this material, also in the towns of Paisley, Kilmarnock, Leith, Perth, and Ayr. The work was executed by Messrs. W. G. Walker & Sons of the latter town, where this class of pavement was first laid, and is so far giving satisfaction. The cost of Walker's tar-macadam paving varies from 4s. 9d. to 5s. 6d. per square yard, according to the locality and area to be laid. Tar-macadam was recently tried in Aberdeen, three thoroughfares being laid with this paving. The aggregate was composed of granite, but, owing to the non-absorbent character of this description of stone, which is quite unsuitable for this class of work, it has not been a success. Three streets which were laid about eighteen months ago showed decided signs of wear, after being in use for little over a year, the surface becoming uneven and disintegrated.

531. **Macadamized Roadways.**—Macadamized roads, although they have no place in thoroughfares subject to heavy traffic, form by far the greater proportion of carriageways in residential quarters of towns and suburban districts, and are generally highly appreciated by the inhabitants. When constructed and maintained in the manner described in Chapter VIII., Part I., they form a very pleasant and satisfactory roadway, affording a good foothold for horses, and are moderately clean under normal conditions of weather.

Macadamized roadways, like a pitched pavement, possess one distinct advantage, namely, a good foothold, so that this description of material can be used on gradients up to 1 in 15 with safety. Owing to the great number and varying qualities of the materials used in making and repairing this class of roads, good results cannot be expected, and the economical considerations entailed under these and other circumstances place them at a disadvantage.

By using a superior class of metalling, properly applied and spread on a solid foundation, and efficiently steam-rolled, this class of roads in regard to first cost, annual maintenance, and general suitability, can now be placed in a better position, relatively with other pavements, than formerly.

532. The life of macadamized roads depends entirely on the amount and character of the traffic, the quality of the metalling employed, and the system adopted in maintaining them. The surface of a road may have to be coated once in every three or four years, while, in many instances, it will require extensive repairs every year and oftener in certain circumstances.

533. This cost of construction will vary, according to the locality in relation to the source of supply of the materials, class of traffic, situation of the road, and method adopted in making it; the price, therefore, may range from 2s. to 6s. per square yard. Once properly constructed, the subsequent upkeep consists entirely of surface repairs, which may be of an extensive nature, or simply occasional patches spread one stone thick where

required, the surface being previously scarified, and the metalling consolidated. Continuous coatings of macadam, steam-rolled, at more or less frequent intervals, is the only satisfactory and economical method of carrying on these operations.

The annual cost of repairing some roads in London, which are now paved, may be here given as being of some interest. The cost of granite macadam was on an average 18s. per ton.

TABLE LVII.

	Annual cost per square yard. s.	d.
Charing Cross,	5	0
Piccadilly,	4	0
Regent Street,	3	7
Parliament Street,	2	8
Westminster Bridge,	2	0

In Liverpool, Sheffield, Manchester, Newcastle-upon-Tyne, Glasgow, and other large manufacturing towns, the cost of the annual maintenance varies from 4d. to 2s. 6d. per square yard, the price of the metalling being from 6s. to 14s. per cubic yard.

As the method of constructing town and suburban roads generally is detailed very fully in Chapter VIII., Part I, while the cost of the different operations is given separately, further remarks on them appear unnecessary.

534. Conclusions.—It will be apparent from the description of the different materials which are at present employed in the construction of a first-class carriageway pavement that it is not an easy matter to decide on the particular description of material for this purpose, suitable for the varying circumstances met with.

Many considerations, apart from the durability of the paving material which may be employed, although this is of the greatest importance, have to be examined closely, as at the present time they enter largely into the selection of a pavement suitable to the many varying conditions and circumstances which exist in most towns. The more important points to be considered are, the nature of the gradients and foothold, description of traffic, width of the thoroughfares, the class of property facing the street, facility for cleansing, noiselessness, smoothness, economy of construction and subsequent maintenance, and even the climate.

In cities and towns where the residential and manufacturing portions are somewhat removed from each other, and where the nature of the traffic and gradients vary considerably, an opportunity is offered for using all recognized kinds of paving material suitable to the particular situation or circumstances.

There is not at present, it may be readily inferred, any one class of pavement which possesses all the properties requisite to fulfil the requirements

mentioned above. On sanitary grounds alone impervious pavements are a necessity which, by reason of the methods adopted in constructing them, limits the use of certain kinds of material where heavy and continuous vehicular traffic have to be accommodated.

585. There is a consensus of opinion that granite setts properly laid form the cheapest and most durable pavement of any. It does not, however, present a smooth and regular surface after a few years' wear, especially when laid with a wide joint, and this is considerably intensified by frequent disturbance of the pavement in connection with repairs to gas, water, and other mains. The principal disadvantages of this class of pavement, however, are that it is noisy, and also that it is liable to become slippery through wear, on which account it is decreasing in favour as a paving material in the fashionable quarters and business thoroughfares of cities and large towns. No doubt the wide joint has something to do with the great noise inseparable from a pitched pavement, as, after a time, considerable vibration is set up, the wheels of vehicles bumping from stone to stone, and causing wear and tear in an excessive degree both in the traffic and in the pavement itself; this vibration may also cause damage to the surrounding buildings.

It is possible that, if granite setts could be economically produced by the aid of machinery, so as to fit close together like a wood pavement, having an even surface and the joints grouted with bitumen, which would make it less noisy, this description of street covering would compare more favourably in this respect with the practically "noiseless pavements"—wood and asphalte. In manufacturing towns where such defects are not of so much consequence, and on steep gradients generally, this pavement still holds its own against all others for the safe foothold which it affords.

586. In large cities where the carriageways are comparatively level, and the residential quarters and manufacturing parts of the town are separated and well defined, pavements of the smooth and noiseless description, such as those formed of wood and asphalte, or some of the patent artificial paving blocks, can be advantageously laid in the former districts, while a granite sett pavement would be more suitable, on account of its superior foothold and ultimate economy, in the latter case where the traffic is heavy and continuous.

As a matter of fact, however, few towns of any importance possess but one class of pavement, and, in many instances, two or more kinds are in use, depending on the locality, the character of the traffic, and the gradients of the different thoroughfares. As a case in point, the streets in the city of Sheffield, extending to 314½ miles, are constructed with every recognized form of paving, with the single exception of compressed asphalte.

587. Soft wood pavements or yellow deal blocks, although much used in the past in the larger cities, and at the present time in many of the provincial

towns of medium traffic, are gradually giving way in favour of the Australian hard woods. The first cost of hard wood pavements is undoubtedly greater than that of soft woods, but the durability and hygienic qualities of this class of paving material are such that it is replacing granite setts and the soft woods.

Hard wood paving laid with a close joint, and the blocks of which have been previously dipped in a bituminous composition, wears very regularly and is practically noiseless; the relative rates of wear for hard and soft woods are stated to be as 1 to 6 in thoroughfares subject to heavy traffic.

538. Asphalte forms an ideal pavement. It is absolutely impervious; it affords no lodgment for filth, and, as it retains its camber, the surface drainage is rapid and effective. It is more easily cleansed than any other pavement, so that, from a hygienic point of view, it stands far in front of all other pavements. It retains a smooth surface, and is preferred by residents in streets where it is laid, because the wheels of vehicles passing over it make but little noise.

Unfortunately for this otherwise excellent pavement, at all events, that formed with rock asphalte, on account of its extreme slipperiness during certain climatic conditions, is disliked by horse owners, who, of course, use the streets most. For this reason rock asphalte cannot be laid on steeper gradients than 1 in 60. On comparatively level thoroughfares this defect is greatly diminished by thoroughly washing the surface, as it is admitted that clean asphalte is not slippery in either a wet or a dry condition.

Sanding the surface has to be resorted to at times to increase the foothold; but has a tendency to wear the pavement, and ultimately results in mud being formed. This is only a temporary measure, however, and repeated applications of sand are necessary at times to render the pavement safe for travel.

The difficulties which beset the earlier attempts to form a satisfactory carriageway pavement of Trinidad asphalte in this country now appear to have been overcome. The undoubtedly better foothold for horses afforded by this description of paving material over that of rock asphalte is very striking, and, should it prove durable under heavy vehicular traffic, the problem of providing a safe, efficient, sanitary, and noiseless carriageway pavement may be looked upon as solved.

539. The pavements which give the longest service should invariably be chosen, as, when other things are equal, it is to be preferred, because the renewal of the pavement in any of the principal thoroughfares of a town necessitates the closing of the street, which causes great inconvenience and seriously interferes with business. Although the first cost may be greater, that which is most suitable for the traffic is the cheapest in the end, as it has the additional advantage that the streets are less frequently closed for renewals.

The concentration of traffic upon subsidiary streets, on account of the renewals to the main thoroughfares, occasions a state of disrepair on those roadways beyond that which would result from the ordinary or legitimate traffic.

540. On the question of safety or comparative slipperiness on granite, wood, and asphalte pavements, the following table, prepared by Mr. Haywood, from exhaustive observations made in 1873, on the accidents to horses on carriageways in the City of London, is given: *—

TABLE LVIII.

City of London: Comparative Slipperiness of Carriageway Pavements.

Pavement.	Distance travelled before a horse fell—in miles.			
	Dry.	Damp.	Wet.	Average of 50 days.
Granite, ...	78	168	537	132
Asphalte (Val de Travers) compressed, . . .	223	125	192	191
Wood (Improved Wood and Ligno Mineral), .	646	198	432	330

His remarks in connection with these observations give interesting details, and are as follows:—

"Slight rain makes both asphalte (rock) and wood more slippery than they are at other times. On asphalte the slipperiness begins almost immediately the rain commences; wood requires more rain before its worst condition ensues. The slipperiness lasts longer upon wood, on account of its absorbent nature, than it does upon asphalte; when dry weather comes after the rain, then asphalte is in its most slippery state, and the horses fall on it very suddenly; on wood their efforts to save themselves are more effectual; wood also is frequently in that peculiar condition of surface in which horses slip or glide along it without falling. A small quantity of dirt upon asphalte makes it very slippery; wood requires a large quantity. Slipperiness can be temporarily cured on both pavements—on the asphalte by sprinkling it with sand, on the wood by sprinkling it with gravel. The result in both cases is dirt. The sand thrown on asphalte helps to wear it out, the gravel thrown on wood tends to preserve it. When a horse falls on asphalte it has great difficulty in getting up; on wood it rises more readily."

* *Report on Accidents to Horses on Carriageway Pavements*, by G. William Haywood (1874).

541. The only other observations of a similar nature carried out, so far as the author is aware, are those made by Captain F. V. Greene in the United States, the results being as follows: *—

Asphalte (Trinidad), ...	583 miles
Granite, ...	413 ,,
Wood, ...	272 ,,

These figures differ from those given by Colonel Haywood, both in their order and relative values, but probably the climate has something to do with this.

542. In thoroughfares crowded with traffic, the continual stopping and re-starting of heavily laden vehicles is very trying to horses, especially when the pavements are in a greasy condition, after a slight shower of rain or during the prevalence of fog. Washing the surface and applying fine gravel to a pitched pavement increases the foothold considerably, while the same treatment of soft wood pavements has the additional advantage of assisting in preserving the timber by reason of the small stones being crushed into the surface and so indurating it. Sprinkling sand on an asphalte pavement greatly increases the foothold, but it is detrimental to the surface, as it helps to wear it out.

543. Table LIX. has been prepared by Mr. Boulnois, and shows the essentials of a good paving material for first-class pavements, based on a theoretical and practical study of the subject.

If a numerical value be given for these properties to the several descriptions of pavement, it will be found that they appear in the following order:— asphalte, granite, bricks, and wood.

544. There is a marked difference between the description of pavements employed in large towns where the financial position ensures that the best form suitable to the locality and interests of the inhabitants can be provided, compared with those in provincial towns and urban districts where, as a rule, the financial resources are limited. In the latter, this, to a great extent, restricts the use of first-class pavements, although in many cases a less expensive class of road covering is sufficient for the purpose. Pitched pavements, with or without a rigid foundation of concrete, are generally adopted, especially in manufacturing towns, where a smooth and noiseless paving is not of much consequence; and when the material is of a durable nature this description of roadway is ultimately the most economical, although the first cost may be considerable. It should, however, be understood that the cheapest pavement in first cost is not always the most economical, because it has been proved that the most suitable for the traffic is the most satisfactory and economical in the end. A heavy annual expenditure for maintenance

* Bryne on *Highway Construction.*

TABLE LIX.*

Table of comparison of merits and objections of different classes of pavements.

Note.—The numbers refer to order of merit.

Description of Pavement.	Ease of Traction.	Foothold.	Cleanliness.	Noiselessness.	Durability.	Economy.	Facility of Repairs.	Impermeability.	Suitability to all Classes of Traffic.	Suitability to all Gradients.	Uniformity of wear.	Appearance.
Asphalte, . . .	1	4	1	2	2	2	1	1	2	4	2	1
Bricks, ...	2	1	3	3	3	3	3	3	3	1	4	3
Granite, ...	4	3	2	4	1	1	2	2	4	2	1	4
Wood, ...	3	2	4	1	4	4	4	4	1	3	3	2

* *Carriageways and Footways*, by H. Percy Boulnois, M.I.C.E.

generally shows that restriction of the initial expenditure in constructing a carriageway pavement has been the main object rather than suitability and efficiency during its lifetime.

545. In districts where the traffic is medium to light, and the thoroughfares comparatively level, tar-macadam may be advantageously adopted. It forms a smooth, impervious pavement when properly executed, and has the additional advantage that when suitable material can be conveniently obtained it can be constructed cheaply.

Ordinary or dry macadam, although the most expensive roadway to maintain where there is a heavy wheel traffic, has the advantage of possessing the best foothold for horses. On light trafficked town thoroughfares a steam-rolled macadam road is the cheapest form of construction, and when properly made with approved materials little mud or dust results compared with traffic consolidated roads, and is the class of roadway generally preferred by residents in suburban districts.

546. The great difficulty in comparing one class of pavement with another in regard to the durability of the material, precludes any definite comparison being made as to their respective lives under varying conditions or of their comparative economical advantages. As this can only be attained by direct observation, it is desirable that such records should be made periodically under proper regulations and in a uniform manner. It is essential that a careful census of the hoof traffic and the wheel traffic be made, so that the actual amount of traffic tonnage, both fast and slow, reduced to a standard, passing over any street, can be accurately ascertained for a given period; this is generally stated in tons weight of traffic per yard of width of roadway per annum. From these data the actual cost of construction and the amount expended for annual maintenance, reliable figures for comparison would be obtained. This census, while applicable more particularly to large cities and towns, would likewise be of great advantage if applied to provincial towns and country districts where there is a considerable amount of traffic passing over the roads. No doubt the amount of tonnage would fluctuate considerably at different seasons of the year, especially in country districts, but a fairly accurate record of the traffic could ultimately be arrived at.

Many records have been kept in the principal cities of the number of vehicles passing along a particular thoroughfare, but the approximate weight of each individual vehicle and its load, and the width of the roadway not being given, the information is obscure and void of any real value, except perhaps as a general statement of facts.

No doubt some difficulty would arise in regard to hoof traffic which, in many instances, causes more wear to the pavement than the wheels of vehicles; still more definite data might be collated, and a standard adopted by which the traffic passing over a road could be calculated.

547. Isolated instances of the amount of traffic and the number of vehicles passing over some thoroughfares in London are recorded, which are here given :—

TABLE LX.

Locality.	Vehicles.	Tonnage.
Westminster Bridge Road, 1899.	8754 (west side) in 12 hours.	334 tons per ft. in width of road in 12 hours (6 a.m. to 6 p.m.).
,, ,,	8014 (east side) ,,	233 tons do. do.
Strand, 1890.	1228 per hour and 15,000 from 8 a.m. to 12 midnight. Omnibuses are included in this number, and vary from 360 to 444 per hour or about 37 per cent. of the total number of vehicles.	
Euston Road, Western end, 1895.	Omnibus traffic equals 7·72 per cent. of the total weight of traffic.	575,544 tons per yard in width per annum.
Euston Road, Eastern end, 1894.	Omnibus traffic equals 31·8 per cent. do., and 19 per cent. of the total number of vehicles. The average number of omnibuses traversing Euston Road is 250 per hour.	411,318 tons per yard in width per annum.
Piccadilly, 1899.	1497 per hour, of which 423 are omnibuses, being equal to about 28 per cent. of the total number of vehicles.	
Cheapside, 1899.	661 per hour, of which 384 are omnibuses, being equal to about 58 per cent. of the total number of vehicles.	
Tottenham Court Road.	661 per hour, of which 487 are omnibuses, being equal to about 74 per cent. of the total number of vehicles.	

In Liverpool the traffic tonnage and annual cost for maintenance per square yard of the different descriptions of pavement, and of the pitched pavements in particular, have been recorded since 1872, the material being from different sources.

548. The following record Table (LXI.) of street traffic is the form adopted in London.

549. Besides the amount of traffic which a carriageway pavement has to sustain, the relative safety of the different descriptions of pavements should be recorded, while the damage done to horses, vehicles, and harness,

TABLE LXI.

Record Table of Street Traffic.

Name of Street.....Class of Pavement.....State of Repair.....Width between Curbs.....ft.....ins.

Gradient 1 in.....Period under observation from (*time and date*).....to (*time and date*).....Name of Observer.....

	Description of Vehicles.											Exceptional Loads, Weight to be inserted.	Horses falling.	Condition of Road at Time of Fall (Wet, Dry, Greasy, Sloppy).
	Omnibuses.			Heavy Dray.	Light Dray.	Heavy Van.	Light Van.	Tradesmen's Shop Vans.	Carriages and Cabs.	Loaded Carts.	Empty Carts.			
	Full.	½ full.	Light.											
	65 cwt.	45 cwt.	35 cwt.	90 cwt.	40 cwt.	70 cwt.	35 cwt.	15 cwt.	15 cwt.	40 cwt.	18 cwt.			
6 a.m.,	...	...	...	...	...	...	...	...	...	...	...	...	...	...
7 ,,	...	...	...	...	...	...	...	...	...	...	...	...	...	...
8 ,,	...	...	...	...	...	...	...	...	...	...	...	...	...	...
9 ,,	...	...	...	...	...	...	...	...	...	...	...	...	...	...
10 ,,	...	...	...	...	...	...	...	...	...	...	...	...	...	...
11 ,,	...	...	...	...	...	...	...	...	...	...	...	...	...	...
12 ,,	...	...	...	...	...	...	...	...	...	...	...	...	...	...
1 p.m.,	...	...	...	...	...	...	...	...	...	...	...	...	...	...
2 ,,	...	...	...	...	...	...	...	...	...	...	...	...	...	...
3 ,,	...	...	...	...	...	...	...	...	...	...	...	...	...	...
4 ,,	...	...	...	...	...	...	...	...	...	...	...	...	...	...
5 ,,	...	...	...	...	...	...	...	...	...	...	...	...	...	...
6 ,,	...	...	...	...	...	...	...	...	...	...	...	...	...	...
7 ,,	...	...	...	...	...	...	...	...	...	...	...	...	...	...
8 p.m., etc.,	...	...	...	...	...	...	...	...	...	...	...	...	...	...

by reason of an irregular surface or a state of disrepair, must not be lost sight of. It is generally admitted that a pavement with a smooth, regular surface means longer life to horses and vehicles, the road surface does not wear out so quickly, and the cost of transit is considerably reduced, but singularly enough the better the class and condition of the pavements the greater is the amount of heavy individual loads hauled over them.

CHAPTER XIII.

FOOTWAYS—KERBS, CHANNELS, GULLIES, PAVING MATERIAL FOR FOOTPATHS.

550. All footways in towns require a kerb at their outer edge, so as to define them and to form a sill for the raised path against which the material that it is paved with may butt.

A kerb is also particularly required to keep off vehicular traffic, and should be of a sufficient height, varying from 3 inches to 8 inches, except at crossings, to prevent surface water in the channels flowing over the footwalk; it also retains the foundation and surface of the pavement. Kerbstones of less height, apart from allowing water to flow over the footway, would render it possible for vehicles to drive on to them, while a greater height than 7 inches or 8 inches is inconvenient for foot passengers. A kerb likewise forms the side of the channel or gutter, and retains the haunches of the carriageway.

551. The materials used for forming kerbs are of various descriptions, but, for first-class thoroughfares having much traffic, granite, syenite, and whinstone are by far the most satisfactory for this purpose, and although expensive in first cost are much more economical in the long run. The other materials used are sandstone, cement concrete, vitrified fireclay blocks, cast and wrought iron.

Granite, syenite, or whinstone kerbs are made in various sizes; where concrete is used for the foundation they are generally laid on their flat, as shown in figs. 124 and 126, the usual size being 12 inches by 8 inches. For the most part kerbs are made 6 inches to 8 inches by 12 inches; they are never made less than 4 inches wide and 9 inches deep, laid on edge, which gives a sufficient hold in the ground for all practical purposes. For comparatively level thoroughfares the blocks are dressed rectangular, but on gradients, or where they are likely to be used as a drag for heavy vehicles, the kerbs are generally splayed off on the front face, as shown at figs. 124 and 126, in order to minimize the grinding action and rough usage likely to arise from the wheels of heavily laden carts and wagons.

552. Stone kerbs should be dressed with a margin draft along both top edges, and hammer-dressed about 6 inches on the face and 3 inches on the back, and to the full depth on the ends or jointing surfaces, while the top surface should be similarly treated, or the blocks may be 'nidged' on the top and sides to the depths mentioned. This ensures a clean, decided junction for the paving material of the footway, and presents a smooth and well-defined surface alongside the channel. The kerb-stones should not be less than 3 feet in length, and when 7 inches or more in width the upper surface ought to be bevelled off, so as to conform with the slope of the footway, and thereby enable rainwater falling on the surface to readily reach the gutters. When deep kerb-stones are employed, as shown at figs. 124, 125, and 126, they are generally bedded on gravel and a layer of sharp, clean sand, and beaten into position by means of a heavy maul or beetle; the gutter side should be further consolidated by using a cramping-iron or iron bar. By such means open spaces are avoided, which, if they existed, would in time tend to overturn the kerb towards the carriageway, and shift it from its upright position. Besides being unsightly, this might necessitate its having to be relaid, entailing additional expenditure. Great care should be exercised in setting out and laying kerbing, both in regard to line and level, as there is nothing more unsightly than badly laid kerb-stones.

553. **Cement Concrete Kerb.**—These can be made in blocks, the concrete being placed in moulds and manipulated by hand or subjected to hydraulic pressure, and laid in position in the same way as stone kerbs, which is preferable, or it may be formed *in situ*. In either case the durability of this class of kerb depends on the quality of the gravel or other material used, and the cement. This description of kerb is generally used when the footway is made of concrete, and is only suitable for streets of light or medium traffic, where it is not likely to receive heavy blows or be subject to the grinding action of the wheels of passing traffic.

554. **Fireclay Brick Kerbs.**—Kerbs of this class, principally of the blue Staffordshire description, are used in many subsidiary streets in provincial towns. The chief point is economy, but, like kerbs made of concrete, they can only be successfully employed in streets of light traffic. Brick kerbs are greatly used in the United States and Holland.

555. **Cast- and Wrought-Iron Kerbs.**—This description of kerb, although of late their use has been more extended, has not been much used in this country. They have, however, been frequently used on the Continent. So far as the wearing point or edge is concerned, they protect the roadway well, but their shape makes them dangerous for pedestrians, owing to their becoming slippery. The cost of these kerbs, their shape, and the difficulties in laying them in a uniform manner appear to have prohibited their use on an extensive scale. Fig. 127 shows a cross section of a cast-iron kerb.

556. The wrought-iron kerb, or edging, is now extensively used in con-

nection with 'concrete *in situ*' pavements. It serves the purpose very well, and has a smart, well-defined appearance. It is economical, especially where there exist old irregular kerbs which require to be renewed. The edging consists of an iron plate 9 inches to 12 inches deep and ½ inch thick, jointed longitudinally where necessary by a cover-plate fixed on the footpath side of the kerb. This kerb plate is fixed in position, as regards line and level, by means of thin rods of iron 18 inches long, which are inserted in the edging-plate every 5 feet, and, projecting into the footway, are kept rigidly in position by being attached or anchored to a batch of concrete on the top of the foundation which ultimately forms part of the under layer of the pavement. The top of the iron plate is fixed so that the finished level of the paving material will correspond with it. Fig. 128 shows a cross section of a wrought-iron kerb or edging.

557. Channels.—Channels or gutters are necessary in connection with footways and carriageways to receive the surface water from the roadway and convey it towards the gullies; they also protect the kerbs from being

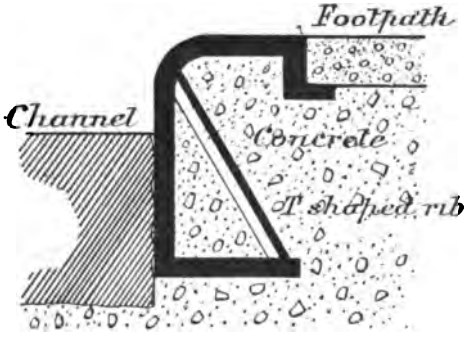


FIG. 127.—Cast-iron kerb.

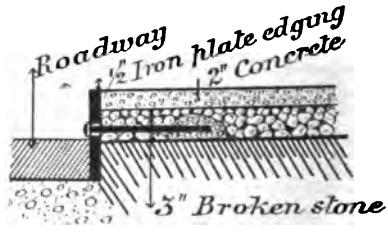


FIG. 128.—Wrought-iron kerb or edging.

undermined, and enhance the appearance of the street. The channels are sometimes formed to the same contour as the roadway, as shown in figs. 125 and 126. The general practice, however, when they are constructed with slabs or setts is to lay them level transversely, as shown in fig. 124, or to slightly dish the upper surface, or to use 'hollow channel,' as shown in fig. 124. When streets are paved with setts, asphalte, or wood blocks, the same class of material is generally employed to form the channels. Setts and wood blocks of the same size as the ordinary paving material, and in some instances of less size, are laid horizontally, instead of transversely, so as to aid the flow of water alongside the kerb. The gutters are made from 12 inches to 18 inches wide, with from 4 to 6 courses of blocks; at times granite slabs are made use of from 12 inches to 15 inches wide and 6 inches thick, square dressed on their abutting faces, so as to fit closely

together, the upper surface being nidged or tooled. This description of material makes an excellent gutter, but it is somewhat expensive.

558. Channels should not be laid with a flatter gradient than 1 in 300, and when practicable they ought to be set so as to show 5 inches of the kerb above it, but of course this will depend entirely on the gradient. On practically level carriageways the channel will vary from 3 inches to 7 inches below the upper surface of the kerb in order to give sufficient fall for the surface water to drain rapidly towards the gullies. Figs. 125, 126, and 127 show the arrangement of channels for different descriptions of carriageway pavements.

559. At crossings or intersections of streets the channels are raised so as to be nearly on a level with the kerb, which is a great convenience to pedestrians. This arrangement, under certain circumstances, necessitates extra gullies, but it is a much more satisfactory method of overcoming the difficulty, compared with that of employing rectangular iron conduits (which have been much used in the past), besides being less objectionable as regards interference with vehicular traffic.

560. **Gullies.**—These are placed at certain intervals along the gutters, and are connected with the sewers. The distance apart will vary considerably, according to the gradient of the carriageway, the nature of the traffic, and the capacity of the gully itself. They may be made of brick, stoneware, or iron, and covered with gratings of cast or wrought iron. The essential points which a street gully should possess are:—

1. The area of open grating must be sufficient to cope with heavy and sudden rainfalls.

2. The grating must be so constructed as to permit of the least possible obstruction or choking on its surface by road detritus, paper, straw, or leaves.

3. The gully must be of adequate capacity to retain the road detritus below the outlet pipe and so prevent its entrance into the sewer.

4. It should have a deep-water seal or trap to prevent the escape of sewer gas, be easily cleaned out, and so constructed that it can be readily cleared by suitable means should a stoppage occur.

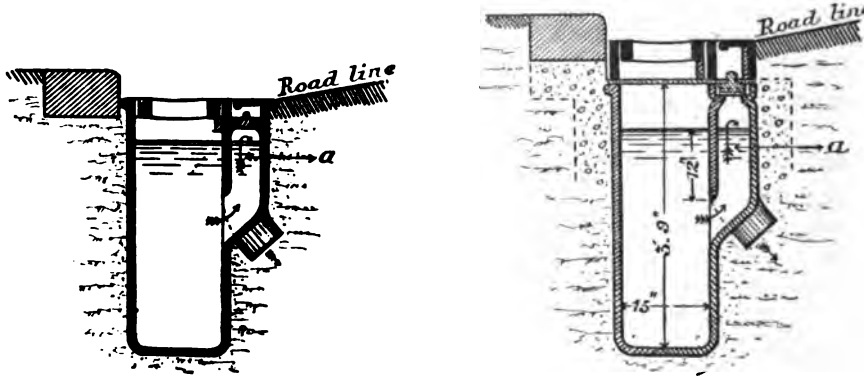
5. The grating should be such that it will form the least possible obstruction to the traffic, and on macadamized roads the outlet pipe of the gully ought to be placed at such a depth below the surface of the roadway that it will be free from danger or injury by heavily laden vehicles and steam rollers.

6. It should be constructed of materials not likely to be damaged by the tools employed for removing the detritus, and it should be made strong and thoroughly water-tight.

561. **Sykes' Stoneware and Iron Gully.**—These gullies are made of granite stoneware or cast-iron, and are circular or rectangular in form.

The outlet connection to the sewer is kept low with a view to avoid any danger of fracture; it has a deep-water seal which prevents untrapping in hot weather, and is so arranged, by means of a tongue or diaphragm, that the water after falling into the gully has to rise over this diaphragm before it can escape, which arrangement arrests all road detritus. Figs. 130 and 131 show this gully, the diagrams being self-explanatory. The cost of these, complete, varies from 20s. to 60s. for circular gullies, and 60s. to 75s. for those of an oblong shape.

562. Crosta's Surface Water Gully.—This gully, shown at figs. 132 and 133, is well designed, and is in every particular a first-class article, and has been largely adopted in all the principal cities and towns. It is made of cast-iron in various sizes, from 7½ up to 25 gallons capacity, is strong enough



FIGS. 130, 131.—Sykes' gully traps.

to withstand the heaviest traffic, and is self-contained and thoroughly water-tight. It is provided with a double trap, and the small area of the water exposed to the atmosphere perfectly seals noxious gases at all times and under all conditions, while it thoroughly intercepts all road detritus.

The smallest size made measures 21½ inches × 18 inches by 26 inches deep, the top measurement being 17½ inches × 14½ inches. The largest size, the capacity of which is 25 gallons, measures 25 inches × 22 inches, and 3 feet 5 inches deep, the dimensions at the top being 21 inches × 17 inches; the outlet pipe for all the different sizes of gullies is 6 inches in diameter.

The cost of these gullies varies from 38s. 6d. to 63s. 6d.

563. There are many other descriptions of gullies made, too numerous to mention, but the following possess considerable merit, and are for the most part manufactured in stoneware, namely:—Doulton's, Willoughby, Wakefield, Priests, and the Gloucester gully; the latter is made with a mud box which

can be easily lifted out and emptied by means of a hook, and is manufactured in cast-iron, the size being 18 inches × 15 inches × 17 inches.

564. Under certain conditions, in many localities large gully pits are constructed so as to retain a considerable quantity of road detritus. These, for the most part, are placed in streets situated on a gradient, and are generally built of brick and lined with cement or asphalte, while at times they are provided with double gratings; the size of the pit may be 3 feet × 1½ feet, and from 3 feet to 4 feet deep. Fig. 134 shows one of these gully pits as used in the city of Liverpool.* It is constructed of

FIGS. 132 and 133.—Ames's Crosta's gully trap.

brickwork lined with cement, the bottom being of York or other suitable flag, while the tongue is made of similar stone.

565. Footways.—The width of footways is generally regulated by the width of the carriageway and the amount of pedestrian traffic passing along the street. This is a matter which should receive considerable attention, so as to avoid, in exceptional cases, excessive proportions for either the footpath

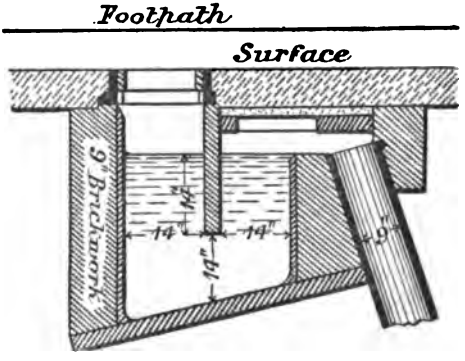


FIG. 134.—Section of gully pit used in Liverpool.

or the carriageway. In ordinary circumstances the footway on each side of a carriageway may be advantageously made ⅛ to ¼ of the total width of the

* *Carriageways and Footways.* By H. Percy Boulnois, C.E.

roadway; the fall from the heel of the path to the kerb may vary from $\frac{1}{8}$ inch to $\frac{1}{4}$ inch per foot, according to the description of the material used for paving the footpath. For concrete and asphalte the former fall is sufficient, while the natural stones, bricks, and such-like materials are laid with the latter fall or a gradient of 1 in 48.

The materials of which the wearing surface of footways are made vary considerably, and these afford an opportunity for selecting a suitable paving under different conditions of traffic and situation.

566. Qualities which Paving Materials should possess.—The qualities which should characterize a good paving material may be enumerated as follows:—It should be durable and smooth without being slippery; it should absorb the minimum quantity of water and dry quickly after rain; it should also be non-abrasive, uniform in texture so as to wear evenly, easily cleansed, have a good appearance, and be economical in first cost.

The different kinds of material used which are suitable for this purpose are divided into natural stones and artificial stones, or compositions, the following being the principal descriptions employed:

1. Natural stones, such as Caithness, Yorkshire flagging, and Arbroath pavement.
2. Asphalte, rock and Trinidad, tar-paving.
3. Concrete, in monolith and slabs.
4. Bricks and tiles.
5. Cork paving, sanitary blocks, and various other compositions.

The selection of the best material which will answer the requirements in regard to situation and heavy pedestrian traffic should be made only after actual trial, although many of the properties necessary may be previously ascertained, such as the absorbent powers, the specific gravity, and rubbing to ascertain the effects of abrasion of the material proposed to be employed.

567. A good foundation is indispensable for footways, and when a natural one does not exist, an artificial foundation must be provided. This may be accomplished by the use of furnace clinkers or cinders, broken bricks, tiles, and freestone shivers, with the addition of proper drainage to dispose of any water penetrating to the underbed of the footway. By using a suitable material for the foundations (which should be well rolled), the cracking or damage resulting to the wearing surface, and which is often attributed to bad workmanship in laying it, will be obviated or at least reduced to a minimum.

568. Of the natural stones used for paving a footway, Caithness flags are considered the best. This description of pavement is very durable, wears evenly over the whole surface, and does not become slippery; it is impervious to wet, and dries quickly after rain; it is not affected by frost, and dust and dirt do not adhere to it readily. It is a very dense material, does not laminate, and can be easily taken up, turned, and re-used when worn.

This description of paving varies from 1½ inch to 2 inches in thickness, as shown in fig. 125; the joints are generally sawn, which facilitates the expeditious laying of the pavement. The first cost is against its general adoption in many of the large towns, although it is extensively used in busy manufacturing centres as Liverpool, Birmingham, South Shields, and Sunderland; it is also much used in Scotland, especially in Edinburgh, Glasgow, and Aberdeen.

569. **Yorkshire Flags.**—These possess many of the essentials of a good paving material for footways, and are generally made from 2½ inches to 3 inches in thickness. This description of paving does not wear smoothly; consequently it affords a good foothold. It is easily worked to curves or irregular lines, and has an agreeable appearance. Like Caithness flags, they can be lifted, redressed, and used again; but the great drawback to Yorkshire flags is that they wear unequally, and are liable to laminate under atmospheric influences, especially in frosty weather.

570. **Arbroath Pavement.**—This description of paving material is much used in Scotland, especially in the larger cities and towns. It varies from 2½ inches to 3 inches in thickness, is of an agreeable appearance, wears evenly, and can be used again by being redressed. The joints are sawn square to the full thickness, which ensures quick and accurate laying.

571. **Laying Natural Stone.**—The different kinds of paving material for footways mentioned should be bedded on the foundation already mentioned, with a layer of lime mortar evenly and truly laid with square joints, which should be flushed up with good mortar.

572. The life of these footway paving materials will of course vary according to the amount of pedestrian traffic. Caithness flags in many instances have been down for fifty years, but twenty-five to thirty years may be considered about the maximum duration for them. It has been stated that in some instances Yorkshire flagging had only a life of from six to seven years, but this probably was owing to a soft description of this class of stone being used.

573. Other natural stones of the sandstone and limestone order are employed locally, such as Pennant, Purbeck, Blue lias, Devonian limestone and Lazonby; the latter sandstone, from the Penrith district, is very durable, and affords a good foothold, and the selected sorts wear very evenly. Granite slabs, which were extensively used years ago, are now seldom laid. They are very durable, but the multiplicity of joints is a serious defect, and they also become extremely slippery. The slabs are difficult to dress and are very expensive.

574. **Asphaltic Footway Pavements.**—Foundations for this description of footway paving should be of Portland cement concrete, six to one, and laid from 3 inches to 4 inches in thickness. The surface of the concrete is smoothed over, and three to four days must be allowed for it to set before

commencing the spreading of the asphalte. The method of laying rock and Trinidad asphalte is very similar to that for carriageways, which has been already described, the only difference being, that the thickness is reduced to $\frac{3}{4}$ inch and 1 inch respectively. Owing to the creeping tendency on footways situated on an incline, the former description of asphaltes, principally Limmer, Val de Travers, and Seyssel, the first possibly being the best known, cannot be laid with advantage owing to the tendency to crack through this cause.

575. Trinidad asphalte, however, when the binder course is introduced, can be laid on footways situated on steep gradients. This material forms a thoroughly smooth, impervious, and durable pavement; it affords a good foothold, is pleasant to walk upon, easily repaired, and can be advantageously used on footways having much pedestrian traffic. This description of paving is shown in fig. 127.

576. Rock asphalte mixed with bitumen and grit, and known as "mastic asphalte," is much used, and is generally laid about 1 inch in thickness. The mixture is prepared in the following manner: From 75 to 63 per cent. of powdered rock asphalte is mixed with 5 to 7 per cent. of Trinidad bitumen, and 20 to 30 per cent. of grit are placed in a large covered cauldron and heated for about five hours. The mixture, which liquefies at a temperature of from 280° to 300° Fahr., is conveyed to the site where it is to be used in 'locomobiles' provided with a fire and agitators, and deposited on the foundation by means of pails, previously heated, and spread with a float. The pavement is finished by being strewn with silver sand well rubbed into the surface. Fig. 127 shows this description of footway pavement.

When the work has to be carried out at a distance from the manufacturing depot, the asphalte is made into flat cylindrical cakes of about 50 lbs. each. These are taken to the site of the work and remelted in small street cauldrons, an allowance of from 3 to 4 per cent. of bitumen being added to the melted mixture to make up for the loss by evaporation. One ton of asphalte will cover an area of 20 square yards, laid to a depth of 1 inch.

577. **Tar Concrete Pavement.**—This description of paving material is much used in suburban districts where the pedestrian traffic is light. The methods of manufacturing and laying vary considerably in the different districts where it is employed.

The process is somewhat similar to that of making and laying tar macadam, only the aggregate used is much smaller, generally consisting of fine gravel or stone chippings. The stones vary in size from $1\frac{1}{2}$ inch to $\frac{1}{4}$ inch gauge, and these are dried by being heated, and a boiling composition is added in the following proportions:—

12 gallons of tar.
½ cwt. of pitch.
2 gallons creosote oil.
1 ton of screened material.

This mixture is spread in layers, the largest sized stones being laid on the prepared foundation and finished with the smallest class of material, each layer being compressed by means of a hand-roller, weighing about half a ton, until a uniform surface is obtained.

For really good work, the material forming the aggregate should be capable of absorbing a certain amount of the tar composition, for which purpose mountain limestone or Kentish rag is the best. If hard material, such as granite or whinstone be used, a bumpy surface is the result, which, besides impeding the drainage, makes a very unpleasant path to walk on. As in the case of tar macadam and asphalte pavements generally, tar concrete paving must be carried out in dry weather, preferably in the spring or autumn, while the success of the pavement will depend to a great extent on the efficient drainage of the underbed.

To add to the appearance of a tar concrete paving, white spar or stone dust is thrown over the surface, rolled in and finished with sand. Like tar macadam for roadways, tar concrete improves by being stored for a few months previous to using it. When applied under these circumstances, the mixture is 'freshened' by the addition of a small quantity of refined tar.

578. Apart from ordinary repairs the surface of a tar concrete footway requires dressing occasionally. This is performed in dry weather by applying hot tar to the surface (previously swept clean), and spreading a layer of sharp sand over it. This will prevent the dressing adhering to the feet of pedestrians, and at the same time form a skin and add materially to the life of the paving. The tar for this purpose, as well as for the concrete mixture, should be well seasoned or refined to ensure good results.

Tar concrete paving is not suited for main thoroughfares in populous centres, its proper place being suburban districts and footways in small towns.

579. **Concrete Paving.**—This class of footway paving may be carried out in monolith, and also by laying prepared slabs; they are for the most part practically the same, being formed of gravel, broken stone, or granite reduced to the size of pea gravel, or $\frac{3}{16}$ inch in diameter, mixed with Portland cement in the proportion of 3 of granite to 1 of cement.

There is an endless variety of this description of paving material made by different firms, a few of the principal kinds being as follows :—

Stuart's Granolithic, laid *in situ* or as flags.
Imperial Stone (Company's), laid *in situ* or as flags.
Victoria Stone.
Adamant Stone.
Jones' Annealed Stone.
Ransome's Stone.
Ferrumite Stone.
Bucknell's Granite Breccia.
Guernsey Granite Concrete.

This description of paving material for footways has made great progress during the last few years, and as most of these are manufactured and laid in a similar manner, with but minor variations, only the principal features of a few will be described in detail.

580. Stuart's Granolithic *in situ* Pavement.—This description of paving, which has been laid in almost every town of importance in this country and abroad, like all others of a similar nature, requires a good firm foundation, as on this depends, to a great extent, the future of the wearing surface or its being able to withstand the pressure of the pedestrian traffic.

The ground is excavated to a depth of 5 inches below the finished level, and upon this is spread a layer about 4 inches in thickness of cinders, gravel, furnace clinkers, broken tiles and bricks, freestone shivers, or other suitable material. This layer must be properly punned or rolled and the interstices filled up, and the upper surface should be 2 inches below the finished surface of the footway.

The pavement is divided into panels or bays varying in width from 4 to 6 feet, separated by strips of wood. Narrow panels are necessary to prevent the concrete forming cracks transversely when a sudden change of temperature takes place, which has been the cause of this description of paving being thrown out of position when laid *in situ* with panels of greater width.

The strip of wood is at times retained, but in most instances it is removed, the alternate bays or panels being constructed after those first laid are set and have become thoroughly hard. A strip of roofing felt is at times introduced between the joints to provide for expansion, and serves the purpose admirably, provided the panels are not laid of a greater width than 3 to 3½ feet.

After the area is divided into bays, a layer of concrete (4 to 1), 1½ inch to 2 inches thick, is spread and well punned with flat-headed beaters, and before this first layer is set a finishing coat of fine concrete, consisting of ten parts of granite chippings, thoroughly washed, to one part of Portland cement, is spread. The concrete should be carefully mixed, water being added only in small quantities. The finishing coat is spread to about a thickness of 1 inch, and well worked to remove all cavities, the surface being then trowelled off smooth. Every alternate bay is finished and allowed to set properly before the intermediate panels are commenced. The wearing surface, when partially set, is finished with an imprint hand-roller, either making indents or forming a grooved or corduroy surface, for the purpose of giving a better foothold. With some descriptions of concrete paving such means of preventing slipperiness is not considered necessary, except on inclines, while at the same time some authorities state that it interferes with the wearing surface of the paving. Fig. 129 shows a cross section of Stuart's granolithic pavement.

Traffic should not be permitted on the pavement till the concrete has

thoroughly set and become hard, and till then the pedestrian traffic should be diverted or accommodated by placing a temporary platform of wood over the surface. In hot, dry weather the concrete, after being laid, should be protected by spreading sand over the surface, or by placing old cement bags, kept thoroughly wet, on the pavement.

581. One objection to this description of pavement for footways is that repairs are difficult to make should the covering be lifted for the purpose of laying or renewing pipes. The greatest objection is the prolonged disturbance of the pedestrian traffic during the time it is being laid and setting, a serious matter in a busy thoroughfare, where shops abut on the footway. This class of pavement should only be laid in good weather, heavy rain or the prevalence of frost being detrimental to its durability.

582. Concrete Slabs.—In consequence of these objections in connection with monolith pavements, concrete slabs, which are free from the defects mentioned, are now frequently used. Victoria stone and many other descriptions of concrete slabs are made in a similar manner; they are formed in wooden moulds lined with metal, to facilitate their being removed when set.

They are composed of broken stone, gravel, and sand mixed with Portland cement and water; in many cases a solution of silicate of soda is added. They are made in various sizes, the most useful dimensions for paving work being 30 inches in length and 24 inches in width, and 24 inches square by 2 inches thick. The process of making the slabs hard and dense is carried out by some firms by subjecting the concrete to great pressure in the moulds.

The aggregate, consisting preferably of $\frac{3}{8}$ inch granite chippings, washed to remove the associated dust, is thoroughly mixed in a dry state with Portland cement, the proportion adopted being three of the former to 1 of the latter. After this has been accomplished, water is added in a careful manner, and the whole is mixed until thoroughly incorporated. The 'compo' is then placed in moulds and worked at the corners and sides with a trowel to ensure clean, accurate arrisses all round the slab, and finished to a smooth surface. The moulds containing the concrete are by some processes subjected to a mechanical movement of a jolting nature, which motion gets rid of many of the air cavities.

The slabs are removed from the moulds at the expiration of two days, and stored so as to become air-dried for seven to nine days, and then, should the process be adopted, immersed in a bath containing a solution of silicate of soda. After being so treated for a week or fourteen days according to the capacity of absorption, the slabs are stacked in the open for some months to season, previous to being used. Fig. 126 shows a footway paved with slabs.

Many manufacturers of these concrete slabs use only one class of

granite chippings, which is produced principally at the quarries in Aberdeenshire, Bonawe, Furness, Leicester, Guernsey, and Quenast (Belgium).

583. **Adamant Paving Slabs.**—This paving material is made of finely crushed Aberdeen granite and the finest Portland cement. The concrete, when properly mixed, is placed in moulds and then subjected to hydraulic pressure. This effectually disposes of both air cavities and moisture, the result being a dense, non-porous, and homogeneous stone or slab, which can be immediately handled. By this process the slabs can be manufactured and laid in the course of a few days; the ordinary sizes made are 3 feet × 2 feet, 2½ feet × 2 feet, and 2 feet square by 2 inches in thickness.

These slabs for paving footways are largely used in Aberdeen, Edinburgh, and many English cities and towns. Paving slabs are extensively made in certain towns from the clinker produced by refuse destructors, mixed with Portland cement. These are not, however, so durable as concrete paving made with granite chipping, but they form a cheap material which is quite suitable for footways in subsidiary streets. Pavements formed with concrete slabs are easily cleansed, and being non-absorbent, dry quickly after rain; they can be expeditiously laid and wear evenly.

584. **Bricks or Tile Paving.**—Bricks or tiles to be of any value as a footway paving require to be of hard vitrified stoneware; they do not form an ideal paving material, but are greatly used in many towns in the Midland counties of England.

Blue Staffordshire, and Buckley bricks measuring about 10 inches × 5 inches × 2 inches deep, with a chequered or diamond pattern surface, are those most largely used; they make a durable pavement when laid on a foundation of concrete.

Owing to the numerous joints, this paving is difficult to cleanse; and when worn becomes slippery and uneven. The appearance of brick paving is not in its favour; it does not make a pleasant surface to walk upon, but it is well suited for many footways in the streets of manufacturing towns. The bricks can be lifted and relaid at small cost, which is a point in its favour, especially where the footways are often disturbed in introducing or repairing service pipes and house connections. The life of this paving is estimated at various periods up to thirty years.

585. Brick paving is much used in the United States as a material for covering footways in the towns where it is extensively employed for carriageway pavements.

586. **Cork Paving and Sanitary Tiles.**—Compressed cork paving for footways are practically noiseless, are not slippery, and are non-absorbent; the blocks measure 9 inches × 4½ inches × 1 inch; they are jointed with a bituminous grout laid on a concrete foundation 3 inches in thickness.

587. The sanitary tiles for footways are made in 8-inch squares or 5-inch hexagons, and 2½ inches thick; they may be laid on a 3-inch concrete

foundation, or on a bed of gravel well punned and a layer of sand. The blocks are laid closely together, the joints being closed by compression under traffic. It affords a safe foothold for pedestrians, is smooth and even, and does not become slippery through wear. It is practically waterproof, dries quickly after rain, and can be quickly and easily repaired in all conditions of weather. It is stated to be durable and economical.

588. Footways situated in country districts are generally formed with from 4 inches to 6 inches of coarse gravel or freestone chips, and finished with fine gravel or the screenings from a stone-breaking machine. Furnace cinders are also used in districts where they can be easily obtained. This description of footways has been treated in Chapter VIII., and serve the purpose very well when properly kept in repair. For suburban districts, and in small provincial towns, tar paving may be advantageously employed where suitable materials can be obtained.

CHAPTER XIV.

SUBWAYS.

589. The construction of subways or conduits under the street level for the reception of gas and water mains, electric wires and other conductors, so as to obviate the perpetual breaking up of the street pavements in order to lay new pipes, discover and repair leakages, or for other purposes, is a subject of considerable public interest and an important element in the obstruction of vehicular traffic. It has received a large amount of attention from time to time, but little has been accomplished up to the present. Recently it has been proposed to construct high-level viaducts and tunnels or subways in addition to forming new and widening existing thoroughfares at important points, as a solution of the congestion of street traffic in London.

590. The ever increasing pedestrian traffic has likewise received attention; foot bridges over the carriageways, and subways with a flight of steps leading to the pavements at important street crossings have been proposed, the latter being the method adopted in connection with the Central London Railway scheme at its terminus in the open space in front of the Mansion House, which point has been aptly described as the "heart of the city."

591. The necessity for subways is evident when it is considered that any examination of the existing mains to ascertain their condition is impossible, especially where many are placed under the roadways, and it is only when undetected leakages, which may have existed for a long period, become apparent, that measures are taken to discover and remedy the evil. The only recourse under the circumstances is to break up the street pavement, an operation which may, in many instances, extend over a considerable area of the thoroughfare, and involve considerable expenditure and inconvenience.

In large cities and towns the annual cost incurred in tracing and making good the leakage of water and gas mains and connections of different public companies must be considerable, while the deterioration of the pipes which must necessarily take place when situated in a subsoil of a variable nature

is also a serious matter. The expenditure thus incurred must be enormous when taken collectively, and must not be overlooked; although when divided amongst many companies it may not appear such a formidable figure.

592. It is stated that in the City of London many of these leakages cost about £20 to discover, exclusive of the actual repairs to the water or gas mains, or the other connections placed under the ground. In most instances the carriageway pavement is irretrievably damaged when disturbed for this purpose, its life being materially shortened, besides leading to possible accidents and causing the greatest inconvenience to the traffic and loss of trade to business people.

In addition to the large annual expenditure connected with the examination for leakages and the subsequent reinstatement of the pavement, the effect of the percolation of water and the escape of gas permeating the subsoil must necessarily create a very unsanitary condition of matters in the surroundings.

593. Early Subways.—One of the earliest attempts to avoid the disturbance of street pavements in connection with laying or repairing pipes under ground, so far as the author is aware, was carried out in Liverpool; it is described by Prof. Rankine.* "One method of obviating this is to provide 'side-trenches,' to contain those underground works, being narrow excavations lined at the sides with brick walls, and situated under the outer edge of the foot pavement, by the flags of which they are covered. The wall of the side trench next the roadway is strengthened against the pressure of the earth by means of transverse walls, with openings in them for the passage of sewers and pipes; and between these transverse walls the longitudinal wall is slightly arched horizontally. The other longitudinal wall of the side trench forms the back of a row of cellars under the foot pavement. The side walls of the cellars are in a line with the transverse walls of the side trench, and act as buttresses to give it stability. In the example given in Mr Newland's report for 1848 the side trench is 13 feet deep from surface of footway to foundation, 2½ feet wide inside, and has cross walls at every 7 feet; the brickwork is one brick, or 9 inches thick. It contains an oval sewer-pipe 27 inches × 18 inches, a 10-inch water-pipe and a 10-inch gas-pipe. Sewers which are large enough to be traversed by men may be repaired by getting access to them through subterranean passages leading into them from trap-doors in the foot pavement."

The earliest subways of any consequence constructed in this country were carried out in 1862 in Southwark Road and Garrick Street, London, and in Victoria Street, Nottingham, in the year 1863. For many years past subways have been constructed in connection with most of the Metropolitan improvements, such as the Holborn Viaduct, Thames Embankment, Charing

* *Civil Engineering*, by Prof. Rankine, pp. 629 and 630, taken from Reports by the Borough Engineer of Liverpool (Mr James Newlands).

Cross Road, Queen Victoria Street, while many have been constructed in existing thoroughfares.

The "side trenches" constructed in Liverpool to accommodate a sewer and water and gas mains appear to have been made for the sole purpose of placing the pipes into them, without any consideration as to the future requirements of renewal or repair.

594. A subway of novel construction has been recently completed at St Helens.* The opportunity of advocating and carrying it out was afforded in connection with the purchase of the tramway system, which it was decided to convert and equip for electrical traction. This decision was further strengthened by the necessity of disturbing the surface of the streets in connection with carrying out these works and for the purpose of renewing the gas and water mains and services, and also the laying of electrical cables. All these circumstances, combined with the narrowness of the streets, made the proposal to form a subway a decided improvement, whereby the whole of the mains and works beneath the thoroughfares could be properly inspected, while the interference of the paved surface and foundations of the streets would be practically eliminated. The latter circumstance alone, brought about by the almost incessant renewing of gas, water, and other mains, would have been in itself an incentive to construct a subway.

This subway, which measures 6 feet 6 inches by 5 feet 6 inches, is, with the exception of a 4½-inch ring of blue brick to form the arch, entirely built of concrete. The side walls and haunches are extended upwards so as to form the foundation of the paving material forming the street, and is about 12 inches above the brick arch; the inclination of the subway follows the gradient of the streets.

No doubt the size of this subway has been determined in view of prospective requirements; at present it accommodates one gas main 18 inches in diameter, two water mains, 10 inches and 6 inches in diameter respectively. Lateral ways are also provided, opening on the footway, through which gas and water pipes can be conveyed where required.

The services leading from the subway are enclosed in 6-inch earthenware pipes on either side of the roadway. The subway proper is constructed close to the kerb on one side of the street; it is provided with gullies at intervals to drain surface water to the sewer. Special provision is made, in case of a burst in the water mains, by placing a valve at the lowest point of the subway and there connected direct with the sewer.

The subway is lighted throughout by electricity, and arranged so as to be used without fear of explosion should a leakage of gas take place; it is ventilated at intervals of 100 feet.

The cost of constructing this subway, although of ordinary dimensions,

* The details in connection with this subway have been abstracted from an article which appeared in the *Surveyor and Municipal and County Engineer*, January 26, 1900.

is stated to have been £7, 2s. 4d. per lineal yard, which expenditure includes the lateral ways and the electric lighting; this is certainly a comparatively small cost for such an outstanding benefit.

595. The subways hitherto constructed in London are deficient in many respects, especially in being too small in most cases for the growing requirements of the city, although in one or two instances a very few mains have been laid in some of them. The most serious objection, however, is that, in the majority of cases, they have been constructed in short unconnected sections of varying size, without any general scheme for carrying out extensions embracing a complete system in any particular district or centre.

596. The introduction of subways of an adequate size for prospective requirements in the principal streets of large cities is necessary for many reasons, but it appears that they are only constructed at present when new streets or improvements on existing roadways are carried out. This, no doubt, is a step in the right direction; but as those thoroughfares are generally considerably wider than the existing streets, the necessity for subways in them does not appear to be so great as at points where there is a congestion of street traffic.

597. Many instances exist where the gas, water, and other mains are crowded into very narrow streets, and sometimes laid immediately below the surface of the roadway. As an instance of this the following may be given:*—In a road at Richmond, which measures 15 feet in width, eight pipes of varying diameter are laid. These consist of two 30-inch and two 21-inch water mains, one 14-inch water main and one river main 6 inches in diameter, besides pipes for gas and telephone wires. It can be well imagined that it is almost impossible to examine, repair, or renew any of those pipes, and the continual disturbance of the roadway for such examinations must keep the surface in a perpetual state of disrepair. It is stated that in one of the London streets, extending to about one-third of a mile, the annual cost in connection with the disturbance and reinstatement of it amounts to a sum of over £200.

The leakage of gas and water mains, which leads to very serious results, besides the enormous loss to the owning companies, would be prevented or at least greatly reduced by the introduction of subways. The leakages of underground mains are mostly due to a small beginning, as, for instance, the joints drip or leak; being removed from sight, an examination is impossible, and it increases until it brings about a collapse in the surrounding ground.

These mains, if placed in a subway, could be examined daily, and any defects promptly remedied; this would lessen danger and effect a great

* "Street Subways for Large Towns," by Charles Mason, *Trans. Soc. Engineers*, 1895.

saving in gas and water, while the repairs, cleansing, and painting of the pipes and general inspection could be carried out periodically.

598. Ventilation.—Objections have been raised that the escape of gas from the mains might produce disastrous results; no doubt this would happen if the gas pipes were not properly inspected and prompt action taken for repairing them when necessary. Any leakage of a temporary nature tending in that direction would be easily obviated by efficient ventilation, which is of the greatest importance in any conduit or subway.

It is reasonable to suppose that the life of gas, water, and other mains would be considerably increased if placed in a subway, compared with being laid in the ground and near the surface of the roadway, where a sudden change of temperature adversely affects them. It has been proved by observation that the air in subways does not vary more than about 5°, while the range of the temperature of the outside air amounts in many cases to about 34°. The range of temperature in existing subways varies from about 40° to 45° during the winter and summer months respectively.

599. The regulations issued in 1893 by the London County Council prohibit the use of naked lights or molten lead in the subways under their jurisdiction, while in the city subways no such restrictions are enforced, open gas lights being in use throughout their length. Such restrictions in regard to the use of naked lights and other matters must seriously hamper the extended use of subways in many districts of London, as the public companies having Parliamentary rights to have their pipes under ground might not be induced to make use of the subways under these conditions.

600. The municipalizing of public companies, which in large cities is a very complex problem, would in all probability obviate many of the difficulties standing in the way of forming subways on a larger scale. If such a course were adopted, these would be constructed, and the mains and other pipes laid, and all the works would be maintained under the jurisdiction of, and be the exclusive property of, one company.

601. Construction of Subways.—The earlier subways carried out in London consisted of a semi-circular arch of brick, 6 feet high, constructed along the centre of the thoroughfare with the sewer underneath, and of laterals or sideways about 4 feet in height, branching off at right angles from the main subway. The more recent subways have been, for the most part, made from 11 to 12 feet wide, and from 6 to 8 feet high; they are built with brick arching, and have laterals placed from 30 to 60 feet apart. Many of these subways are quite inadequate for the requirements of the district in which they are situated, while others are only partially made use of. This clearly points, especially in busy streets and where many thoroughfares converge, to the utilizing of the greater part of the width between the kerbs or in very wide carriageways, the forming of a subway on each side of ample size, and connecting them at suitable intervals by means of sideways

or laterals. By either of these methods duplicate mains could be placed near the adjoining properties on each side of the street and connected at convenient points across the thoroughfare through the laterals. This arrangement would be preferable to having only one gas or water main in each street, and admits of sections being disconnected for repairs or for a burst pipe, and shortens the distance for the house connections.

It would be necessary to provide drainage by means of gullies in the floor of the subway and laterals (to receive washings and water from the mains should they require to be emptied) properly connected to the sewer; house drains would also require to be specially arranged for. Provision for the street drainage, and connections for street lamps, water posts, and fire hydrants would obviously be requisite also.

Vaults under the footways have been advocated, which no doubt in many business thoroughfares with underground warehouses would serve for the purpose of storing goods, and from that a considerable revenue might be derived.

602. The system of construction generally adopted in making underground railways in towns might be advantageously adopted, for the forming of subways, or some modification of that method. The side walls could be constructed of concrete or brickwork of sufficient thickness and height, according to the particular circumstances of the case, and covered with steel decking of dimensions sufficient to carry the roadway and the vehicular traffic safely. This form of construction could be applied to either class of subway above mentioned, and would give the maximum area possible, and be especially advantageous for hanging small pipes from the roof instead of having them carried by means of brackets fixed to the walls. The roofing and walls would require to be made thoroughly waterproof, and the floor laid with concrete or asphalte.

603. For adequately carrying out repairs or renewals, tramways should be laid in the subways and properly equipped with rolling stock for conveying and handling heavy pipes, either when laying a new line of mains or renewing an existing one. The entrance to the subways would require to be situated in a side street, in close proximity to them, and conveniently placed, a special access leading to the yard or court connected with the subways being provided and kept constantly closed, except for the admission of authorised workmen and the delivery or removal of pipes and other materials for repair.

604. Cranes or hoists of sufficient capacity for handling heavy weights would require to be provided for lowering or lifting material to or from the trollies or bogies on the tramways. These tramways could be operated either by manual labour, cable, or electricity, and the whole subway illuminated by electric light, and parcelled out into short sections for daily inspection or for repairs. It would be imperative that the entrance to the subways be

under the direct control of the authorities, whose servants would admit only workmen provided with passes, and this would also guard against the admission of anyone to the subways for illegal purposes.

605. Undoubtedly many difficulties will arise as to the best form of construction to be adopted in any particular case, so as to satisfy all concerned. The great number of pipes in many of the existing streets would likewise create difficulties in constructing subways, but in no case are these insurmountable, as many of the underground railways carried through some of our large cities have successfully dealt with similar conditions.

606. The cost of construction, apart from the difficulties and vested interests, has hitherto been the great obstacle to forming subways in London, as well as to their introduction into other cities. Those already constructed in the Metropolis—that is, the single subways—have cost from £25 to £40 per lineal yard, while a triple subway proposed by Mr. C. Mason in 1895, and occupying the full width of a 50-feet street, was estimated to cost £80 per yard.*

These subways are built of brick arching, which not only increases the cost of construction, but also causes considerable delay and annoyance during the execution of the work. By adopting side walls which could be built in trenches (which would not interfere with the traffic to any great extent), and employing steel decking properly coated and kept in repair, the work, in the author's opinion, would be more expeditiously executed as well as more economical. Sections of a street could be lifted, the girders then placed in position and the pavement relaid, leaving the soil between the walls to be removed to the necessary depth, and the gas and water mains and other connections to be re-arranged in the subway by degrees. This arrangement would remove to a great extent the apparently insurmountable difficulty which is at present cited as militating against the forming of subways.

607. The first cost of construction, which might be fairly urged against the introduction of subways, would ultimately prove to be a considerable saving when the expenditure incurred in tracing leakages and repairing breakages, the enormous loss of water and gas, the cost involved in reinstating the roadway (which at times can only be termed replacement), the great loss to business people through delay, and the 50 per cent. increase in the life service of a pavement are considered.

608. With reference to subways for pedestrian traffic, the best example of this kind hitherto executed is in connection with the Central London Railway at the Bank Station, Mansion House.

This public subway, which has been constructed by the Railway Company, is situated immediately under the street pavement, and is of an oval shape in plan. There are six entrances to the subway for ordinary foot

* "Street Subways for Large Towns," by C. Mason, *Trans. Soc. Engineers* (1895).

traffic, not only to the Bank Station, but for the purpose of proceeding from one street to another at this extremely busy and crowded spot.

The several entrances are situated at the following different points:—(1) on the pavement in front of the Royal Exchange, and following a north and west direction; (2) on the pavement in front of the Union Bank; (3) on the pavement at the junctions of Queen Victoria Street, Poultry, and Walbrook. On the south and eastwards (4) at Mansion House Place; (5) at the north-east corner of the Mansion House; and (6) on the pavement in front of the Liverpool and Globe Insurance Company's office. The subway then joins the starting-point under the pavement in front of the Royal Exchange.

This subway for foot-traffic is 15 feet wide, lined with glazed tiles and covered with steel decking and concrete, and the whole length is illuminated with electric light.

As the subways are placed immediately below the surface of the street pavements, the flights of steps leading to the footways are of easy access, an arrangement which is of immense benefit to pedestrians.

Another subway, placed directly under that just described and of a similar width, has been constructed for the purpose of accommodating gas and water mains, electric light wires, and sewers.

RECAPITULATION.

609. There is no finality in road repairs. The great problem is to reduce the wear from wheel traffic and the effects of weather to a minimum. Many circumstances exist which require careful consideration, and the details involved, if properly carried out, will tend to lessen not only the tractive efforts of horses, which is a destructive element in itself, especially on steep gradients, but also the cost of construction, and economy in the subsequent maintenance of the roads will be promoted. Likewise, if a system of carrying out the work is adopted whereby the road covering will have a life service of several years compared with that under the method of repairing them annually, the inconvenience, vexatious delays to traffic, and damage to vehicles would be materially lessened, if not altogether avoided.

One of the principal questions involved in laying out a new route, as also in the improvement of many existing roads, is the facility with which traffic between the terminal points to be united can be conveyed, and the consequent economy of the operation. Easy gradients, so far, tend to this end, but the prospective traffic over the road will determine what extra expense is permissible in order to obtain them. Great irregularities of level should be avoided if possible, as the tractive power required to carry a given load is mainly dependent on the steepest gradients passed over, and will be proportionally in excess of that needed for the easier gradients.

It is not difficult to understand, on referring to Table III., p. 34, that the force required to haul a load up a gradient of 1 in 24 is twice that needed to move it on a level. A horse can exert twice his ordinary strength for a short period of time, and is therefore able to take the load up such a gradient for a moderate distance, but beyond such distance it will require either extra help or a reduction of the load.

The extra cost of transport due to steep gradients is increased by anything which impedes traction along the road, such as an irregular or bumpy surface, or a covering of mud. On a practically level road having a hard and smooth surface the cost of haulage may be taken at from 4½d. to 6d. per ton-mile for continuous work, while on roads, the surface of which is covered with metalling (continuous or in isolated patches), or mud, or is

otherwise in bad condition, the cost will be raised to 8d. or 10d. per ton-mile. This is, as may be supposed, caused by the limitation of the loads hauled, the decreased speed, wear and tear of horses and vehicles, and the necessity for making more trips to transport a given weight or employing more horses to accomplish the work.

As the selling price of all commodities includes the cost of carriage, the condition of the roads must have a corresponding influence on the welfare of a community.

The durability of a road or street covering affects the ratepayer directly, and consequently it is an all-important matter. Durability and economy are not always promoted solely by using a superior description of material for the covering of a road or street; it is necessary, and in many instances of greater importance, than the matter of the wearing surface, to secure a proper and solid foundation, efficient subsoil and surface drainage, combined with easy gradients. These conditions demand careful construction and efficient maintenance, while all the materials employed should be the best obtainable, and the methods of procuring, manufacturing, and applying them should be those which will promote economy.

The congestion of vehicular traffic in large cities creates great inconvenience and delay, while the loss of time caused by the latter must amount to a considerable sum annually. Although this does not occur to any great extent in country districts, still, badly laid-out roads, apart from the condition of the surface, with steep gradients and sharp turnings, greatly inconvenience the traffic and add to the cost of transit. These adverse conditions could in most instances be removed, and the durability or wear-resistance of the road surface increased.

The cross-country road described at p. 52 is a case in point, and is typical of many of those in this country. It is obvious that, by laying out a new road properly, one horse may be able to perform the work of two, while many existing roads could be improved and similar results obtained by reducing gradients or deviating the line of road and cutting off dangerous corners. County Councils, however, have not hitherto been disposed to carry out improvements in this direction, and, apart from the heavy strain occasioned to horses travelling over this class of roads, such roads will prove a serious drawback in many parts of the country to the introduction of motor vehicles as an economical means of transit.

Comparatively level stretches of road should be avoided, as the cost of maintenance is increased compared with those having a minimum gradient of 1 in 80 or 1 in 100, owing to the better drainage of the subsoil and the surface, while the tractive effort of horses is not materially affected on such an incline.

The foundation of a road is of vital importance, and should therefore be carefully constructed. The drainage, often carried out in a very

indifferent manner, should be provided for by laying stoneware pipes with proper inspection eyes at convenient points, so that their efficiency may be tested periodically.

Telford's and Macadam's methods of forming a foundation are too expensive for general application, and indeed cannot be adopted under certain conditions, while, to make a Telford foundation a success, specially prepared stones are necessary, and these it may be difficult to obtain in most districts.

The paved foundations generally carried out by Telford, and adopted to some extent at the present time, may be advantageously dispensed with, and a bottoming of hard core or whinstone broken to 3-inch or 4-inch cubes applied. This method of construction, when the stones are spread to a sufficient thickness to meet the requirements of the case, makes by far the most successful and economical foundation. The name 'hard-core,' however, is generally applied to all kinds of material, including bricks and rubbish of a miscellaneous description. When such materials are made use of for the foundation of a road, satisfactory results cannot be expected, while the durability of the surface will be affected, even although it should be covered with superior metalling procured probably at great expense. The formation of the roadway should be consolidated previous to applying the bottoming material, which must be steam-rolled, the joints being filled with sand, any slacks or depressions being made good as the work proceeds. Artificial watering should not be permitted until the later stages of the rolling, and then, if necessary, only to a limited extent.

New roads have not been undertaken to any extent in recent years in this country; consequently, experience of the beneficial effect of the method of construction described is limited. Where that has been adopted, the decreased expenditure for maintenance is very marked, when compared with other roads in close proximity and resting on the same description of subsoil and subjected to similar traffic. Where such differences as to the condition of a road and its relative cost of upkeep arise, the most natural procedure is to make a thorough examination of the covering material and also of the foundation of those roads which are unsatisfactory, so that their condition can be ascertained.

In the majority of cases it will be found that the foundation is in a very irregular and unsatisfactory condition, so that durability and reduction in the cost of maintenance will be looked for more in the direction of reconstructing the foundations of roads than in a lavish expenditure on metalling. Many roads, supposed to be constructed on Telford's and Macadam's system, will, on examination, be found to contain more soft or soluble matter than wearing material. It is difficult to assert whether these roads were deficient when constructed, or have become so through neglect; still the fact remains that in many instances they are very deficient in the essentials which constitute a well-made road. Casual observations, where a

trench is cut across a road for the purpose of laying pipes in connection with water, gas, or drainage works, amply show this condition of matters, and on many roads it is not to be wondered at that the cost of maintenance is not proportionate to its condition and durability in relation to the amount of wheel traffic passing over it.

The beneficial results obtained by lifting and reconstructing a piece of bad road not only promote economy in maintenance; the improved surface makes traction easier, and consequently lessens the cost of transit.

The complete separation of all soft material from the stones forming a road is absolutely necessary, while the consolidation of the earth formation, and the bottoming and the top-metalling separately is indispensable; durability can only be expected to result from this method of construction combined with the employment of material of a superior description.

All large stones forming the foundation of an existing road should be removed and broken to regular size, spread to a uniform thickness, and consolidated by rolling. Material of an inferior quality, such as ordinary sandstone or stones of a soft description, should be removed; good results cannot be expected by using freestone, especially when of a soft character, for bottoming roads, as, being of an absorbent nature, alternating frost and thaw penetrating the crust of a road will in time disintegrate such material, when the top-metalling will be pressed into the foundation, and an irregular and unsatisfactory surface will be the result.

All the smaller stones should be screened from the larger pieces of material, and, if suitable, used as metalling. Any deficiency in the thickness must be made good by applying extra material of an approved quality, such as the trap rocks generally. It is infinitely better to lift and reconstruct the foundation of a bad piece of road, and introduce proper drainage, than to expend large sums on surface repairs.

Efficient rolling, that is, the degree of consolidation necessary to form a solid mass with just sufficient binding left to ensure cohesion of the metalling, is of great importance, and tends to promote durability of a road surface.

Binding should be of a light description and not liable to be affected by frost when in a damp state. The use of an improper material for binding purposes, such as ordinary earth or soil of a clayey nature, will cause great destruction to the road surface during adverse weather; consequently, a coat of metalling consolidated when an inferior binding is used, is not so durable as a coating consolidated with sand or loamy sand, even when the same description of macadam is made use of.

The controlling factors in connection with roads are first cost and the amount expended annually to maintain them efficiently. This points to obtaining a supply of cheap and suitable materials, so that economy of construction and repairs, and durability, may be promoted. The obvious necessity at the present time, owing to the altered condition of trade and

traffic, for obtaining a higher standard of perfection in road maintenance likewise demands that this class of work should be carried out on more scientific principles than formerly, and by the adoption of labour-saving appliances.

The cheapest methods of obtaining the materials necessary for constructing and repairing roads have already been pointed out; and, briefly stated, the quantity of metalling which can be procured by the aid of machinery for the same expenditure is double that of hand-produced macadam.

That the rolling of a coat of metalling (as averred by some people) is a luxury to those using the highways, but involving expenditure additional to that of the former systems of road maintenance, is an untenable contention, when it is considered that steam-rolling, including the collateral charges, amounts at most to 8d. per ton of macadam consolidated. The loss caused by abrasion by the wheels of vehicles when the metalling is spread in isolated patches and consolidated by the traffic is equal to 30 per cent. of the quantity applied; therefore, the value of this loss, when the material is supplied at 3s. per ton, is about 11d. When the road metal costs 5s. per ton, then the saving on this account is 10d., after allowing for the expense of rolling. This shows a clear saving in favour of consolidating the metalling by steam-rolling. Besides, further economy is possible, owing to the coating being left in a hard, compact, and smooth condition, which also promotes durability.

The continual increase of traffic over the roads at the present time, the general adoption of cycles and motor vehicles for travelling either on business or for pleasure, require a stronger road and a better surface. The increased cost of labour necessary for preparing and applying the material, and the subsequent care of roads, has opened up an extensive field for the application of mechanical appliances. Many of the machines hitherto employed in connection with road work have not been quite satisfactory, but inventors and engineers, as in all other branches of applied mechanics, have placed reliable labour-saving appliances on the market, so that a great service has been rendered to those engaged in road work, and also to the public for whose use the roads are maintained.

The proof that work in connection with macadamized roads can be accomplished by the use of machinery for one-half the cost of hand labour is irresistible; consequently, in those districts where power drills for quarrying and other appliances have been introduced, a command of cheaply produced materials is easily obtained.

Probably a lack of experience has militated against the more extensive adoption of such appliances (especially rock drills), which points to the necessity for engineers and surveyors taking every opportunity of acquiring experience from the results obtained where these modern labour-saving machines are in daily use, and have proved not only successful but economical.

Metalling can be produced by stone-breaking machines at one-half the cost of hand labour. Many objections have been urged against them,

but, like all innovations, stone-breaking machines, although their introduction has been slow, are now greatly used and are increasing in number. To keep a road roller constantly at work requires a large daily supply of macadam, and it is only by the aid of machinery in providing the necessary quantity, that successful and economical rolling can be carried on. Of all the machines comprised in a road maintenance plant, the stone-breaker requires the most attention. It is an easy matter to turn out a bad sample of macadam, even with a modern machine; the class of rock, method of feeding and regulating the movements, and many other details, which can only be found out by experience, have a marked influence in producing a cuboidal sample of road metal.

Many surveyors and others maintain that machine-broken metalling is crushed, starred, rounded, and made flaky. No doubt the latter may take place when the rock is dealt with by an unsuitable machine, or by bad management, but generally speaking the defects mentioned do not exist to any extent.

To add to these observations the author would just refer to the results obtained from macadam broken by machinery compared with the case of hand-broken metal, in so far as economy, durability, and a good surface are concerned, and which are detailed at pp. 285 and 290.

Scarifiers for breaking up macadamized road surfaces preparatory to reforming and coating are almost as essential as rollers in connection with road work. A machine which will loosen a macadamized road more expeditiously and thoroughly than can be performed by manual labour at $\frac{1}{14}$ to $\frac{1}{10}$ the cost is a decided advantage. Experience shows that beneficial results arise from the use of such a machine, and it is easy to establish the efficiency, financially and otherwise, of the modern mechanical road scarifiers. Especially is this the case when refacing roads, of which the surface has become irregular or cupped, if the crust contains a sufficient quantity of metalling. This, in many instances, will obviate the necessity of applying a fresh coat of macadam, which is a comparatively expensive operation.

To insist that a coat of metalling should be consolidated by rolling would appear on the eve of the twentieth century to be contrary to the generally accepted ideas of the material advancement in other and kindred matters. This is not the case, however, and in many counties it is questionable if more than 50 per cent. of the metalling applied annually is consolidated by rolling.

The author maintains that, except probably on by-roads, to keep a road in a sound condition, every patch or coat of metalling laid on a road should be consolidated by rolling immediately after it is spread. This at times may be somewhat difficult to accomplish, especially in districts subject to severe extremes of weather during a portion of the season, such as alternating frost and thaw, or where the work, previously arranged with great care, has

to be modified to suit other arrangements. It should nevertheless be the constant endeavour of those engaged in road work to maintain the surface of a road so that the travelling public may only know by the appearance and the improved conditions that repairs or improvements are being carried on, without their having the disagreeable experience of bumping and jolting when passing over the isolated or continuous coatings of loose macadam, or feeling at 'sea' on the highway, instead of travelling in comfort.

If the surface of a road is maintained in a smooth and hard condition, durability is increased, and, consequently, economy is promoted. The question of tractive force exemplifies the true economy of a road in good condition. On a well-constructed road, and having a smooth surface, the resistance which a horse has to overcome is only one-half that on a road kept in moderate repair.

The construction of railways has so far checked the progress of improvements on roads generally, the result being a penalty in the form of providing animal power to surmount the steep gradients, which prevents any cheapening of transit in carrying goods between railway depots and the outlying villages and agricultural districts.

The question of cheap internal transportation is one of great importance, and it is perfectly certain that railways require to be supplemented by some form of traction which will put them in proper communication with the outlying localities. Light railways in certain districts may tend to accomplish this, but it is more in the direction of mechanically propelled vehicles, suitable for travelling over roads, that any real benefit may be looked for. Motor vehicles, which can readily be made to work under favourable conditions, will, to perform the transit of goods cheaply, require to travel at a considerable speed; therefore suitable roads, that is, with easy gradients and smooth surfaces, are indispensable to successfully demonstrating the economic advantages of the automobile.

There is, unfortunately, no general law for regulating the width of wheels of vehicles. Stringent by-laws regulating this are a necessity, when the damaging influence of heavy weights on narrow tyres are considered, or of very broad wheels, carrying proportionately heavy weights, only partially in contact with the surface of a well-made road.

610. In the event of motor vehicles wholly, or even partially, superseding horses in conveying goods and heavy loads over the highways, then the great difficulty of maintaining the roads in first-class order will be surmounted. As each wheel of a motor car, to attain speed and minimize vibration, will have solid or pneumatic tyres, or tires, the action of such on the surface of a road will reduce attrition or wear to a minimum compared with the hoofs of horses and the iron tyres of vehicles at present in use. The insufferable noise caused by iron tyres on hard pavements clearly demonstrates the need for a wheel with an elastic tread, and therefore this would provide a practically noiseless wheel.

Motor vehicles are generally provided with pneumatic tyres which yield to, and consequently absorb, the vibration caused by irregularities on the road surface, by reason of the compressed air in the tube extending round the periphery of the wheel and acting as a continuous spring. These tyres for motor vehicles are manufactured by special machinery and are made thicker at the tread, where naturally the greatest wear takes place, and where there is the most liability to puncture; they are further strengthened by the application of woven canvas insertion.

For light motor vehicles this appears to be all that is necessary, the area of support of the single pneumatic tyre on each wheel being sufficient.

It is when there is a concentration of heavy loads on the four wheels, which is the number motor cars usually have, that the small area of wheel contact presents a serious difficulty in solving the problem of conveying heavy goods by means of automobiles. It has been suggested that, like railway rolling stock, more wheels might be introduced or be constructed on the bogie principle, so as to distribute the weight over a greater bearing surface.

This difficulty might also be overcome, when the present number of four wheels is used (which is the best form for use on the highways), by introducing two or more pneumatic tyres on each wheel. This would distribute the loads equally over a considerable area of wheel contact, the tyres being compressed or deformed in accordance with the actual weight brought upon them in relation to the contour and irregular nature of the road surface traversed.

It need hardly be pointed out that should this much to be desired form of traction, combined with pneumatic wheel tyres, be mechanically successful, the surface wear of roads, once properly constructed, will be decreased greatly, while the sanitary condition of roads and carriageways will be improved. Under these circumstances, it will be possible to attain the standard of excellence set up by cyclists, and it may be observed that the nearer to perfection the condition of a road surface attains, the cost of maintenance will be proportionately decreased.

If motor vehicles supersede horses, particularly in regard to conveying heavy loads, it is just possible that some other description of binding may be necessary in consolidating macadamized roads. The pumping action or suction created by pneumatic tyres, especially when propelled at a high speed, causes a considerable movement of the fine particles, or the material which acts as an agent in the cohesion of the metalling, which on being displaced will convert the coating of metal into a loose mass of stones.

No doubt this objection can be overcome by artificial watering when necessary, a matter receiving too little consideration on country roads at the present time. This will cause additional expenditure beyond that of present requirements, but the cost of providing this will be infinitesimal

compared with the great saving effected in the repair of roads, which, it is confidently expected, will take place by the introduction of automobiles.

611. Comparisons are frequently made of the expenditure of maintaining roads in different counties and districts thereof. In making these comparisons it must be remembered that, unless they are based on similar conditions, the results are of little value. Variations in the character of the soil or the general contour of the country, remoteness from quarries where good stones may be had, the methods adopted in procuring and applying the macadam, and, at the same time, the exceptional traffic due to the industries of particular districts, all militate against uniformity of results. Comparisons of an approximate nature, however, can be made when certain particulars are given, such as the average annual expenditure per mile, amount of material applied each year, and the cost per cubic yard or ton of the metalling. To properly analyse the cost of macadam applied per ton, it is necessary to know the average distance it is hauled, or the cost of transit, and it is here where the difficulty arises, as no statistics exist as to this particular item. Assuming, however, the distance to be the same whether the metalling is furnished by the aid of machinery or by hand labour, then a direct comparison between the two methods of production can be made, the material in either case being prepared ready to be conveyed to the roads under repair.

Taking the average cost of metalling prepared by hand labour at 3s. per ton, and that for obtaining and manufacturing the same size of material by mechanical appliances at 1s. 6d. per ton, but exclusive of haulage (which would be practically the same in each case), shows a saving of 50 per cent. on the cost of production.

If the average quantity of metalling applied each year be 50 tons per mile, then the saving on that length of road would be £3, 15s., or, should the quantity required amount to 100 tons per mile, then the difference would be £7, 10s. per mile in favour of macadam prepared by machinery. Thus for every 100 miles of road the saving would be £375 for the former quantity, and £750 on that of the latter. In other words, in a county, or district of a county, having a length of roads extending to 300 miles, there would be an annual reduction, in the cost of supplying the metalling, of £1125 for quarrying and breaking when 50 tons per mile are applied, and £2250 if 100 tons be the allocation per mile of road each year. If the metalling is consolidated by rolling, then a further saving is effected of from 25 to 30 per cent. of the price of the macadam, less the cost of rolling, compared with macadam rolled in by the wheels of vehicles, by reason of the loss caused by abrasion during the long process of consolidation.

The demand which existed in byegone days for skilled workmen to act as foremen in applying the patches of metal does not apply to any extent when the work is carried out by modern methods, so that the objection

formerly raised in many districts that too much metal and too little labour are used is a thing of the past. The subsequent saving in labour on surface work, when the methods alluded to are carried out in their entirety, is shown to be, on an average, 50 per cent., where the annual allocation was, on the patching system, about 50 tons per mile. Besides these financial benefits, a great source of annoyance and danger is removed by the absence of loose stones on the surface of roads which are efficiently rolled, while mud and dust are reduced to a minimum.

The annual cost of repairing different roads in many counties in England has increased considerably since the initiation of the County Councils. This is attributable in most instances to the unsatisfactory condition in which the roads were at that time. It was necessary to apply a greater quantity and better description of metalling at, in most cases, an increased cost of production, in order to bring them into a satisfactory state of repair. This strengthening process has been taking place gradually, and years may elapse before the large mileage of roads, formerly neglected, will be placed in a state of repair equal to that of the roads which have been maintained consistently in good order for many years past. In all probability, had the combined methods of producing the metalling been adopted, the roads could have been strengthened and improved in surface within a reasonable time, and certainly at less expenditure.

The increased cost of repair alluded to, varying from 6 to 90 per cent., which is applicable to many counties in England, does not apply to the roads in Scotland generally. The 'Road Trustees,' under whose management the roads were prior to 1879, had years previously given practical consideration to efficient and economical maintenance by sanctioning the introduction of steam-rollers and labour-saving appliances. Any increase in the expenditure for road repairs in the principal counties of Scotland has been brought about by the greater amount of vehicular traffic, which, indeed, may be said to have developed to an enormous extent all over the country since the abolition of tolls, but especially in districts where the roads were in a good state of repair.

612. With reference to the annual expenditure for the maintenance of roads, the following particulars, in tabulated form, show the cost per mile and the other items which are necessary for comparison, so far as can be ascertained, for the principal counties of England and Scotland.

Large sums of money are voted annually by the Government for the relief of local taxation.

In England £3,339,517 was received from the Exchequer for this purpose in 1897–98. The county and urban roads in England and Wales extend to 25,747 miles. The annual expenditure for maintenance, etc. of main roads and bridges, including payments to District Councils, amounts to £1,962,460. The county main roads cost £58, and those in

Cost of maintenance per annum of roads in different counties, exclusive of establishment charges.

Counties.	Cost per mile of road.	Metalling applied per mile.	Cost of Metalling per ton.
ENGLAND—			
Bedford (1896–97)	£39 15 11	42	11/6
Buckingham (1896–97)	60 0 0	44	12/- granite 4/- gravel
Cumberland	37 4 7	...	...
Derby (1896)	72 8 10	...	...
Hants	31 0 0	...	...
Kent	112 0 0*	...	...
Leicester	56 0 0	...	...
Northumberland	37 13 0	...	...
Nottingham	54 0 0	...	...
Norfolk	32 0 0	...	10/4
Salop	38 0 0	...	...
Somerset	45 10 0	...	...
Stafford	75 0 0	...	...
Surrey	90 0 0	...	...
Sussex (E.)	67 0 0	...	...
,, (W.)	50 0 0	...	...
Warwick	45 0 0	66	6/5
Westmoreland	27 0 0	...	...
Wiltshire	48 0 0	...	...
Worcester	50 0 0†	...	...
Yorks (E.R.)	60 0 0	...	...
,, (N.R.)	40 0 0	...	...
SCOTLAND—			
Clackmannan	54 0 0	93	5/6
Dunbarton (Eastern), 1899	49 0 0	99	5/5
,, (Western), ,,	34 0 0	54	6/6
Fife (Cupar Division), 1899–1900	18 0 0	58	3/2
,, (St Andrews ,,), ,,	23 5 0	51	4/5
,, (Kirkcaldy ,,), ,,	34 7 0	90	4/9
,, (Dunfermline ,,), ,,	44 0 0	82	5/10
Forfar (Dundee District), 1899	32 0 0	85	4/3
East Lothian (Eastern), 1899	20 0 0	41	6/-
,, (Western), 1899–1900	29 0 0	56	6/6
Midlothian (Suburban), ,,	98 0 0‡	223	5/1
,, (Lasswade), ,,	38 10 0	79	5/10
,, (Calder), ,,	34 0 0	78	5/3
,, (Gala Water), ,,	17 0 0	39	4/5
Perth (Perth), 1899–1900	27 0 0	63	4/2
Renfrew (Lower), ,,	31 0 0	52	6/3
Stirling (Central), ,,	23 0 0	4[illegible]	5/3
,, (Eastern), ,,	36 0 0	70	5/7

Note.—The expenditure on roads previous to the advent of the Coun[illegible] Councils and the employment of machinery was if anything greater than at the present [illegible]ime. The vehicular traffic has increased considerably, the value of rateable subjects has [illegible]n in manufacturing localities, while it has decreased in agricultural districts.

* This high figure is due to the heavy traffic and densely-populated areas near the Metropolis.

† Near Birmingham the cost rises to £200 per mile.

‡ The expenditure on the main road leading east of Edinburgh averages from £267 to £450 per mile per annum.

urban districts £96 per mile. The expenditure for management amounted to £509,512 in the year 1897–98.

The 'Grant in Aid,' which must be devoted entirely to the relief of the road rates, amounted to £35,000 for Scotland last year. The 'Equivalent Grant,' which may be applied to the relief of the road or other rates, amounted to £161,912 for the year ending 15th May 1899.

The extent of roads under the jurisdiction of County Councils in Scotland amounts to 22,337 miles, and entails an annual expenditure for maintenance of £396,336, and for management £35,557 for the year 1897–98. This is, on an average, an annual cost—for maintaining the roads classified as highways—of fully £20 per mile.

The allocation fixed for each county and the districts thereof is calculated on the expenditure incurred on the highways, after specified items have been deducted, so that in districts where repairs of the roads are carried out on the old and costly methods of procuring the metalling by hand labour, applying it in patches and allowing the traffic to consolidate them, receive comparatively the largest grant. These methods of carrying on the work, therefore, are at present indirectly encouraged by the Government, and not allocated, as they should be, according to results. It may therefore be anticipated that sooner or later something in the nature of Government inspection of the highways will take place.

The most suitable description of paving material for carriageways is, under existing and prospective conditions of traffic, that which makes an impervious pavement, and is durable and smooth, while the absence of slipperiness, particularly for horses, is of considerable importance. Asphalte complies with all these requirements, except, perhaps, slipperiness when the surface of the pavement becomes greasy through not being thoroughly washed and cleansed. This consideration will entirely disappear should automobiles supersede animal power, as they no doubt ultimately will do for traction purposes, when the droppings inseparable from horses traversing the thoroughfares, which go to make a greasy surface, will be minimized; therefore the sanitary condition of roads and streets will be considerably improved, while repairs to the pavements or road covering will be materially reduced, and economy effected.

613. Congestion of Traffic in Thoroughfares.—The enormous increase of vehicular traffic in our cities is a problem which is exercising the minds of engineers and others. It has been remarked (and no doubt there appears to be some evidence for the statement), that the introduction of motor cars will to a certain extent alleviate the congestion in busy thoroughfares, by reason of the longitudinal distance monopolized by each unit of traffic being reduced by 50 per cent. compared with the present-day vehicles and horses harnessed thereto. It must be borne in mind, however, that the introduction of motor vehicles will cheapen the cost of transit of most

commodities; consequently, it may be reasonably expected to have a beneficial influence on certain articles of commerce which at present cannot be profitably conveyed by team labour. This points to an increased traffic by reason of the reduced cost of haulage, and practically leaves, as at the present time, the widening, rearrangement, and construction of new thoroughfares the pressing problem it has been for years past.

With reference to the congestion of street traffic in the Metropolis, some observations on the scheme advocated by Sir J. Wolfe Barry in his paper on "The Internal Traffic of London" may be given. The proposals in that paper are intended to relieve certain districts in the Metropolis of the delays experienced at present by business men generally, and the loss of time or the earning value of conveyances that take place in many thoroughfares almost hourly.

"In the matter of street improvements in London also, one cannot but notice an almost entire absence of grasp of a large subject, and in the history of the past forty years we look in vain for any new arterial thoroughfares traversing inner London from end to end, and proportioned in width to the demands upon them at different parts of their route. On the contrary, we find in the new streets, as in the old ones, that the nearer they are to the heaviest of the traffic, the narrower they were in absolute dimensions. Cheapside, Fleet Street, Piccadilly, the Strand, Marylebone and Euston Roads remain very much as they were fifty years ago, when the traffic was a mere fraction of what it is now . . . . most at least of modern street improvements seemed piecemeal and patch-work enterprises, narrowed to the very least dimensions which would pass muster, and without any but the most meagre provision for the future, or, except in the case of Regent Street, the slightest attempt at systematic artistic treatment. In fact, there had been and is now a hitherto incurable *petitesse* in dealing with such matters in London, which is a great contrast to what we saw in foreign cities of far less importance and wealth . . . . It is to be carefully borne in mind that the want of accommodation for traffic in London streets is not merely a question of grumbling of those who suffered from it, but involves many other considerations . . . . such as loss of money in the delays of men of business, loss of time to vehicles and horses, the practical impossibility of introducing cheaper and more expeditious means of transit, like electric trams, and the great want of free circulation of air. My plea is, then, that to meet the traffic of London, what is wanted is not so much additional railways, underground or overground, traversing the town and connected with the suburbs, but wide arterial improvements of the streets themselves. Strictly urban railways, or rather trains that only traverse the town itself, though carrying immense numbers of passengers, have not dealt with the question and will not produce the desired result of relieving the streets; on the contrary, they tend to add to the congestion from the point of view of both urban movement and suburban influx . . . . street

improvements in London should be considered as a whole and in a large minded way, unless we are to be doomed to perpetual disappointment. A scheme of new main thoroughfares, of adequate width for present and future traffic, should be laid down, and realized as time and finance will permit. There should be continuity of effort towards radical amelioration by the construction of great main lines of through communication as distinguished from merely local improvements, and all local improvement should, as we have seen was the case in Paris and other foreign cities, be so devised as to form parts of a harmonious whole. Apart from wide streets, a matter which has been too much lost sight of, is the provision of means for allowing the north and south traffic to cross the east and west traffic with the least possible confusion. If these views of the future requirements are correct, we want, in my opinion, one new and spacious thoroughfare east and west, about 120 feet wide—that is to say, as wide as Whitehall opposite the Horse Guards. . . . Leaving the Bayswater-road near Westbourne-terrace, following the line of Wigmore-street to Russell-square behind the British Museum, thence to near Broad-street station. In addition, there should be two or three thoroughfares north and south, slightly less in width, which should be carried over the east and west route by bridges at the points of intersection; and all these new routes should have a raised or sunken road for bicycles, so that they should not mix either with vehicular or pedestrian traffic. The cost of such a work doubtless presented rather an alarming prospect, for a street 120 feet wide and 4 or 5 miles long must mean many millions of money, though the recoupment from the new frontages would be very important. Such, however, is the kind of undertaking required for the London of the future. The heavy expenditure should not affright us, for it would be repaid by the increased facilities both for trade and pleasure . . . . I cannot but think that the relief of the present congestion of our streets by a well considered enlargement of the arteries of London is a subject which must commend itself as of primary importance to the whole city, nay, more, to the whole nation."

This great thoroughfare from west to east, including subsidiary connections, would be 5½ miles in length The proposals of Sir John W. Barry included special provision at six main points for dealing with the cross traffic, and these are as follows:—

"(1) *Hyde Park Corner.*—In this case the west and east traffic would pass under the stream of traffic going north and south by means of a broad sunken road, leaving the Knightsbridge-road on the north side, and rejoining Piccadilly on the south side. A strip of land of an area of 3·1 acres would be required from Hyde Park and from the Green Park, and practically no buildings would be affected. It would consequently be a cheap undertaking.

"(2) *Piccadilly-circus.*—This is a much more difficult and a highly expensive work. The north and south traffic would cross under the west and

east traffic by means of a central sunken road descending from the north end of the Regent-street quadrant, opposite Vigo-street, passing under Piccadilly-circus and emerging in the Haymarket, the portion under Piccadilly-circus and Coventry-street being in tunnel for a length of some 180 yards, with openings for light and air.

"(3) *Ludgate-hill.*—In this case the north and south traffic would be crossed over the east and west stream by means of a low viaduct and bridge. The natural way of dealing with this crossing would be to cross the east and west lines over the north and south, as the gradients of Fleet-street and Ludgate-hill lend themselves to that arrangement. But the railway bridge across Ludgate-hill necessitates the other plan of crossing, unless a very formidable work, somewhat like the Holborn viaduct, were undertaken, which, apart from cost, would no doubt be a better mode of dealing with the traffic, and would have the great advantage of avoiding the inclines of Ludgate-hill and Fleet-street. Setting this aside for the moment as too expensive, and dealing with the more modest scheme of crossing the north and south traffic over Fleet-street, the proposed viaduct would leave New Bridge-street on the west side and join Farringdon-street on its west side. It would involve interference with a certain amount of valuable property, but the existing frontages would be to a great extent preserved, and, of course, new frontages would be created . . . .

"(4) *Oxford-street and the south end of Tottenham Court-road.*—At this place the west and east traffic would cross over Tottenham Court-road on the north side of Oxford-street. The properties are not extremely valuable, as it would be possible to avoid the Oxford Music Hall and other important buildings fronting Oxford-street by keeping the new high-level road about 150 feet to the north. The gradients might involve the raising of the level of Oxford-street opposite Rathbone-place some 2 or 3 feet; otherwise, no considerable difficulties would be encountered.

"(5) *Wellington-street, Strand.*—In this case the crossing ought to form part of the present scheme of the London County Council for their new street to Holborn, if it is to be a really successful work. The gradient of Wellington-street clearly indicates that the north and south traffic should cross over the Strand. With the exception of the Lyceum Theatre, the property is not specially valuable. The County Council do not think much of theatres, for they are going to acquire, as above indicated, four in connection with the street to Holborn and Strand improvement. The crossing street would ascend from the corner of Tavistock-street and Wellington-street by easy gradients, keeping to the west side of the latter street, and descend by a grade of 1 in 30 to rejoin Wellington-street at the north end of Waterloo Bridge.

"(6) *The passing of the north approach of Southwark Bridge over Upper Thames-street.*—This is a work which speaks for itself, and presents no

serious difficulties. The crossing street would continue the level of the north end of Southwark Bridge and would be parallel to and to the east of Queen-street, descending to rejoin the existing level at the corner of Cannon-street and Queen-street."

The cost of these improvements would amount to a considerable sum, but the value of the new frontages created would in course of time be such as to relieve the ratepayers of any ultimate financial burden.

The inconvenience sustained, expressed in money on the one hand, or the saving which would be effected annually by the inhabitants of London by the proposed improved communication on the other hand, has been worked out in detail. The statistics obtained by Sir John W. Barry as to the delays to all descriptions of traffic consisted of the enumeration of vehicles passing along some of the principal thoroughfares. The results of these are as follows:—"The countings on which the financial value is based were taken in October 1898. It is found that in one hour 992 vehicles passed Cheapside, 1228 the Strand, 1497 Piccadilly, and 661 Tottenham Court-road, the number of pedestrians varying from 3910 at Piccadilly to 6358 at Cheapside. Similarly, it was found by another enumeration that the number of omnibuses varied from 384 an hour at Cheapside to 487 at the junction of Oxford-street and Tottenham Court-road. It might thus be assumed that on these four routes there was an hourly traffic during the working part of the day of 1750 omnibuses, 1500 cabs and carriages, and 1000 carts. Taking an average of nine hours a day as the period during which three of the routes were overcrowded, and in the case of Piccadilly allowing eleven hours, the fact was arrived at that, on these four routes only, 16,650 omnibuses, 14,900 cabs and carriages, and 9700 carts and other vehicles were every day delayed by the crowded state of the streets. The absolute amount of retardation presents some difficulty, but from observations it is found that in different parts of the four main streets alluded to it varied from 10 per cent. to 44·8 per cent., as compared with the speed in unimpeded parts. Therefore, I consider that 20 per cent. would be an under-estimate of the retardations on these routes. Assuming the value of the time of vehicles to be 4s. an hour for an omnibus, 2s. 6d. an hour for a cab, and 2s. for a cart, and reckoning ten passengers in each omnibus at 9d. an hour, one and a-half passengers per cab and private carriages at 3s. an hour, it would appear that the traffic on these four streets involves £1631 an hour; hence a delay of 20 per cent. meant a loss in respect of vehicular traffic only of £880,740 per annum. The traffic of the Euston-road and Queen Victoria-street, if we are to include the chief east and west routes, might be put at 15 per cent. of the above figures, while the traffic delayed in crossing these four chief routes might be taken at 20 per cent. of the figures for the east and west streams. As to a pedestrian traffic (25,514 individuals in all per hour in the four streets under consideration),

I come to the conclusion it is delayed one-third as much as vehicular traffic, or 6·6 per cent., and if 4d. an hour for each individual were assumed, we arrive at an annual loss of £65,000, allowing for females and non-wage earning persons.

"To sum up, therefore, the annual loss on the various routes discussed was: Trade interests, £900,000; vehicular traffic, £1,189,000; pedestrian traffic, £65,000; total, £2,154,000. I do not pretend these figures could be more than an attempt to express in money the inconvenience sustained by Londoners through narrow, overcrowded streets, and I should not have attempted to estimate the money value, except for the purpose of seeing something of the relation between capital and revenue. That a very large amount of money is being wasted will not be denied, nor can it be doubted that the loss was getting worse and worse every year. But, neglecting this consideration and capitalizing the present loss, whatever its true figures might be, at thirty years' purchase, we can see that many more millions of expenditure in improving the facilities for traffic on the north side of the Thames than I have estimated would be commercially justifiable. I feel sure that this is taking a low view of the financial aspect. Impediments to trade could not be appraised by merely taking the value of vehicles, horses, and drivers, and the wages and salaries of passengers, and, besides, there were many other matters which I have left out of account, such as the impossibility of tramways, the danger to bicycle traffic, the safety of travellers, and all the æsthetic considerations and influence on pleasure traffic which our continental neighbours, at least, value highly, and for which they made streets and boulevards that utterly shame the meanness of London thoroughfares." *

614. *Viagraph.*—The viagraph is an instrument for taking an autograph record of road and carriageway surfaces. It is the invention of Mr. J. Brown, Belfast, and by its use valuable information of a reliable nature may be obtained of the comparative unevenness of road surfaces under varying conditions of traffic, and those which are repaired with different descriptions of material, and by different methods.

The viagraph is in principle a straight-edge about 12 feet long and 9 inches wide, applied continuously to the road surface, along which it is drawn. The main frame contains an apparatus for recording on paper a profile of the road surface tested, and the sum of unevenness is indicated by a numerical index. A lever pivoted to the main frame carries on its free end a serrated wheel (road wheel) which, when in operation, rises and falls over all the irregularities of the surface. These movements of the road wheel are transmitted by means of a lever and link to a pencil which records their motions autographically on the paper passing round the recording drum. The paper on which the profile is made is carried under the profile

* *Journal of the Society of Arts*, Nov. 1898 and Nov. 1899.

pencil and round the recording drum by means of a worm and wheel which rotates it and is connected by a shaft and bevel gear with the road wheel. The paper is thus drawn from the stock-roll drum, passed round the recording one, and is wound-up on a receiving drum.

The datum line or, in other words, the position of the lower part of the straight-edge or runners in relation to the portion of the road surface situated between the parallel edges, is represented by a second pencil line, which corresponds approximately with the point of the profile tracing pencil. The closer the position of these two points or lines is, the more perfect will the road surface be.

The sum of the depths of all these depressions constitutes the numerical index of unevenness. This is shown by an index counter, which is operated by cords and rubber bands running in grooved pulleys, and properly fixed to the lever on the road wheel, which, in following a depression or other irregularity of the surface of a road, rotates a small wheel, the movement being transmitted to the index counter and there recorded.

For the purpose of comparing one section of a road with another, it is obviously necessary that the same unit of length be adopted, which will give in feet per mile the sum of the irregularities. The length of road for these tests is fixed at 88 yards, being $\frac{1}{20}$ of a mile, and according to the scale, 33 inches of paper are run off in obtaining the profile, and, by an arrangement in the recording drum, a bell rings when that distance along the road has been traversed.

It is unnecessary to cut off the diagram sheet when one autograph record has been made, a vertical line drawn with a distinctive mark being all that is required. Any number of profiles can therefore be made in a continuous manner during one or more days' operations, and by reference to the field book the particular section can be identified, when the sum of unevenness can be marked on each.

The autograph record is represented on the paper full size vertically and on a scale of $\frac{1}{8}$ inch to one foot horizontally. The cost of this instrument is £21 complete in case with glass cover.

It is possible to get a good profile by the viagraph on a road maintained in a very ordinary manner by selecting the best portions of the surface and deviating from a straight line. The small width of the viagraph practically limits the profile to the narrow track over which it traverses.

To obtain reliable data as to the condition of a road surface the viagraph must be used in an intelligent manner, and to arrive at an average figure representing the unevenness, it is necessary to take two, three, or more diagrams parallel to each other along the road at a fixed or definite distance apart. These points, both for starting and finishing, should be measured and noted so that profiles can be taken from time to time in exactly the same line as the previous ones. Unless a number of autographic records are

taken, parallel to each other, along a road to arrive at an average, especially when a portion of the surface transversely is considerably worn, it is possible to get very variable results, and consequently remarkable differences, in the profile of a road of nominally the same character.

It is necessary to affix the date and year on the diagrams along with a note and measurements signifying at what particular part of the roadway the profile has been obtained. This not only avoids confusion, but gives a reliable diagram showing the profile and the amount of unevenness per mile of road at a glance. The time occupied in operating the viagraph might be urged against its use, but in these days when perfection in road surfaces is demanded, it appears desirable that records of a definite nature should be collated.

It has been remarked that the condition of a road can usually be determined by sight or otherwise, and while this is true so far, still it is of a transitory nature and no definite or positive results are attainable without the aid of the viagraph. Opinions as to the state of roads often differ, and disputes often arise from the same cause, so that the instrument will in all probability serve a good purpose in enabling such differences to be settled. Especially would this be the case when the maintenance of roads is executed by contractors or where main roads are repaired by Urban Councils on payment from the respective counties, in which cases the opinions of those interested vary so greatly. Not only in these particular instances, but in controverting complaints, the viagraph promises to have a good future before it.

An accessory to the viagraph, and working much on the same principle, for taking transverse sections of a road surface, would be of great value to surveyors. If such an instrument could be devised to record autographically in inches the contour and irregularities of the surface of a road transversely, such an invention would probably be of greater assistance to those engaged on road work than the longitudindal profiles obtained from the viagraph.

In working the viagraph it is necessary to have a sufficiently long piece of twine attached to the front end, so that the man in hauling the instrument along does not lift the point, which would otherwise be the case, and cause it to follow a serpentine course, and thereby represent an incorrect autograph record of the road surface.

Like the other tests for efficiency connected with road work, and for comparison generally, it would be necessary to establish a standard of excellence from the results obtained by the use of the viagraph.

In the author's opinion, after experience gained in working this instrument over many miles of road and under varying circumstances, a standard of fitness or smoothness of 15 feet of unevenness, or variation from a regular plane, per mile of road might be safely adopted. This might be

fairly considered equal to bicycle excellence, and at the same time considered, as an average, the standard surface for macadamized roads.

Proceeding to fix the numerical value so as to embrace all conditions of road surfaces, the following might be adopted for general use:—

Numerical Index of Unevenness in Feet per Mile.	Condition of Road Surface.
15,	Excellent.
30,	Good.
45,	Fair.
60,	Passable.
80 to 100,	Bad.

With reference to the actual profiles of macadamized road surfaces and the amount of unevenness on those tested, the following information may be given.

Victoria Embankment.—The autograph record of this thoroughfare was carried out between the Temple railway station and Temple Gardens; the amount of unevenness, at the time when the test was made, being at the rate of 102 feet per mile. A portion of the profile is shown in fig. 135;* the vertical depths are full size while the horizontal lengths are represented on the scale of $\frac{1}{8}$ inch to one foot.

This road is usually in a very unsatisfactory state of repair, so that the autograph record representing the profile and amount of irregularity of the surface will not appear extraordinary, nor will it surprise those who have travelled over it by any of the usual modes of conveyance.

Leatherhead and Guildford.—This is an example of a road surface which is considered almost perfect; it was tested by the viagraph on the recommendation of Mr. Shipton (Secretary, Cyclists' Touring Club) as an ideal road for cyclists. The sum of unevenness on this road amounts to from 12 to 14 feet per mile; the profile of the surface is shown in fig. 136.

These two autograph records distinctly show in a graphic manner the remarkable difference which may exist upon the surface of different roads and even on lengths of the same road.

The author has taken numerous profiles of road surfaces by means of the viagraph on different descriptions of macadamized roads, and the results of these indicate in a very decided manner the advantages of steam-rolling in effecting a regular and smooth surface. Admittedly, this is generally recognized, but the convincing manner in which the state of the surface of roads is shown by the autograph records and its graphic evidence on the subject also point out the relative merits of the different systems adopted of repairing them in any district.

* Taken from *Specification*, Sept. 1899.

Road *A*.—Fig. 137 shows the profile of a section of road situated on a level; the record of irregularity or unevenness of the surface from a true plane is at the rate of 9 feet per mile. This is the best average record yet obtained by the author by the use of the viagraph. It may be mentioned, however, that the material composing the crust of the old road was scarified, lifted, and screened, a fresh coat of metalling 3 inches deep was then applied and the serviceable stones of the screened material spread over this after the new coating was partially set by the passage of the roller. The road was finished in the way described in Chaps. VII. and VIII. The profile was taken one month after the road was rolled, and the result as indicated is an average of five different autographs run parallel along the road, the full width operated on being 18 feet.

Road *B*.—The record of unevenness on this road situated on a gradient of 1 in 30, with medium traffic, was 12 feet per mile six months after it was rolled.

Road *C*.—Fig. 138 shows the profile of a road having a gradient of 1 in 40. The autograph record was taken one year after the road was rolled; the unevenness amounted to 16 feet per mile. The wheel traffic on this road is particularly heavy at certain periods of the year.

Road *D*.—This is a practically level road resting on a clay subsoil and repaired with material of a tough nature but deficient in hardness, otherwise a soft description of macadam.

This road was steam-rolled as in the previous instances; it showed by the viagraph an amount of unevenness, after four years' wear by heavy wheel traffic, equal to 55½ feet per mile. It is about to be repaired again by applying a superior description of metalling, although at comparatively great cost, and steam-rolling the coating.

Road *E*.—This is a traffic-consolidated road, a profile of which is shown in fig. 139; the sum of unevenness is at the rate of 41¾ feet per mile, which amount of irregularity would have been considered years ago, and previous to the introduction of steam-rollers, a first-class road surface.

The following particulars may be mentioned with reference to a portion of road which had a service of eight years after being rolled; last year it was re-coated and rolled a second time. This unfortunately was done somewhat late in the season (namely, the beginning of November 1899). The autograph record of the old surface gave a sum of unevenness of 50 feet per mile, while immediately after coating and rolling, and drawing the viagraph over the same part of the road, the amount of unevenness was at the rate of 13¼ feet per mile. The metalling was then in a somewhat green state, and when in that condition was subjected to frost which continued for some days.

In endeavouring to prove numerically, what is so well known from observation, that, under the conditions mentioned or where a road rests on a wet or damp subsoil, the effect of alternating frost and thaw materially alters

the surface of a road, even when it had formerly a smooth and regular contour: In this instance the sum of unevenness rose to an amount which was equal to 45 feet per mile; the effect of the frost was such that it penetrated the full thickness of the coating, or a depth of 4 inches. The surrounding ground was perfectly dry, so that the effect mentioned was due entirely to moisture (through the artificial watering) which the metal coating contained immediately after being rolled. After thaw set in, the roller was repeatedly passed over this portion of the road to fix the metalling which had been displaced and loosened by the combined action of the frost and the hoof and wheel traffic. The viagraph was drawn over the surface at the same spot after the new coating was dry and in a hard state. The record of unevenness then amounted to 22 feet per mile.

These results summarized are as follows:—

Road surface previous to being metalled and rolled, 50 feet of unevenness per mile.

Road surface after coating and rolling, 13¼ feet of unevenness per mile.

Road surface after coating and rolling but affected by frost when in a moist condition (frost penetrated full depth of coating), 45 feet of unevenness per mile.

Road surface after thaw, the surface being rolled again, 22 feet of unevenness per mile.

This clearly shows, and in a conclusive manner, what may be expected from the effects of frost acting on the crust of a road covering which is either of itself in a moist state, or when the drainage is defective. It may appear strange, but nevertheless the peculiarity is amply borne out in practice, that consolidated coatings of metal, not thoroughly dried before the advent of frost, will considerably alter the actual contour and regularity of a road surface which was previously a well-finished piece of work. Further, the road cannot be restored to its original state even by additional rolling; the only means of accomplishing this, but it appears undesirable to do so, is to scarify the surface and re-form it, and again consolidate the coating by rolling.

It is needless to point out, what is graphically depicted in the autograph records, the great reduction of vibration and concussion to which vehicles are subjected on roads the surface of which gives an unevenness of 15 feet per mile, compared with one which amounts to 80 or 100 feet per mile.

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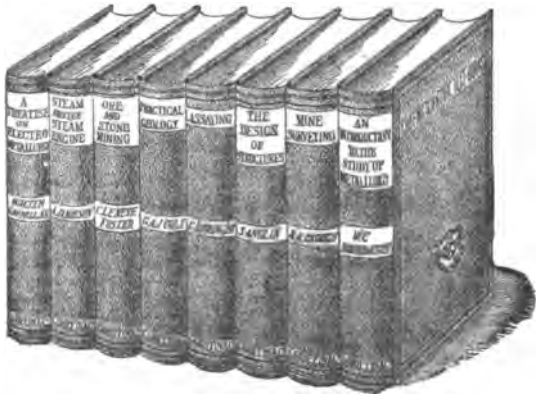

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